THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant. —*Novum Organum, Præfatio.*

VOLUME THE FIFTY-SIXTH.

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ERRATA.

P. lxxxi *is wrongly numbered* lxxxii.
P. 62, top line, *for* Pl. V *read* Pl. IV.
P. 123, 3rd line from top, *for* Abey-Cwmhir *read* Abbey-Cwmhir.
P. 580, 18th line from top, *for* south-west *read* north-east.

EXPLANATION OF THE PLATES AND TABLES.

PROCESS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES,

BESIDES THOSE IN THE PLATES.

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PART 1.

C. A. White

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EDITED BY

THE ASSISTANT-SECRETARY.

[**With Nine Plates, illustrating Papers by Dr. J. W. Gregory, Dr. G. J. Hinde, Mr. H. Lapworth, Prof. T. T. Groom, and Dr. W. T. Blanford.**]

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TO BE HELD AT BURLINGTON HOUSE.

SESSION 1899–1900.

1900.

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[*Business will commence at Eight o'Clock precisely each Evening.*]

THE

QUARTERLY JOURNAL

OF

THE GEOLOGICAL SOCIETY OF LONDON.

Vol. LVI.

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1. *On the* Cornish Earthquakes *of* March 29th *to* April 2nd, 1898. By Charles Davison, Sc.D., F.G.S. (Read November 8th, 1899.)

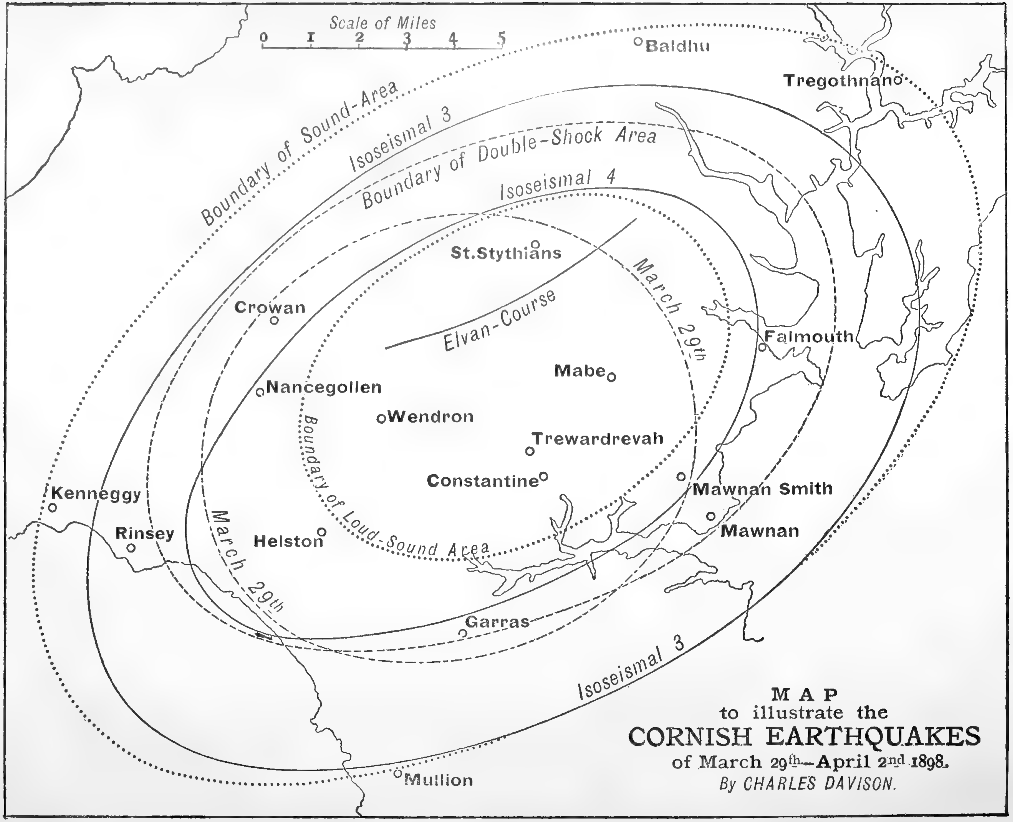
[Map on p. 2.]

On March 29th and April 1st & 2nd, 1898, three slight earthquake-shocks were felt in the south of Cornwall. Their importance lies chiefly in the unusually clear evidence which they furnish, with regard to the origin of the double series of vibrations in one of the shocks, and to the continuous displacement of the seismic focus along the surface of the originating fault.

It is possible that, at about the same time, there may have been other shocks or earth-sounds; but none, so far as I am aware, was noticed by more than one person. At Constantine, which is about 2 miles from the centre of the area chiefly affected, subterranean rumblings were heard on twelve occasions, ranging from six days before to three days after the principal earthquake on April 1st. Two other slight shocks, accompanied by a faint rumbling sound, were also observed on April 10th—one at Helston at 1.45 p.m., the other at Mabe at about 4.30 p.m. I have tried in vain to obtain other records of these reported shocks, and their seismic origin cannot, therefore, be regarded as established.

Earthquake of March 29th, about 10.25 p.m.

Of this earthquake I have only 9 accounts from 7 different places, namely, Crowan, Garras, Helston, Mabe, Mawnan Smith, Nance-



MAP
to illustrate the
CORNISH EARTHQUAKES
of March 29th–April 2nd 1898.
By CHARLES DAVISON.

gollen, and St. Stythians; while at 8 other places it is stated that neither shock nor sound was observed.

The boundary of the disturbed area is indicated on the accompanying map (p. 2) by the broken-and-dotted line. It is $10\frac{1}{2}$ miles long, 9 miles broad, and contains 74 square miles. This curve being so nearly circular, it is useless to give the appearance of precision to any estimate of the direction of its longer axis; but that it is approximately parallel to the axes of the isoseismal lines of the principal earthquake is obvious from the map. The centre of the area is $1\frac{1}{4}$ miles E. 8° S. of Wendron.

The earthquake consisted of two distinct shocks, the first of which occurred at about 10.25 P.M., but probably a little before, and the second about five minutes later. The intensity (according to the Rossi-Forel scale) was 4 at Helston, and less than 4 at Crowan, Mawnan Smith, and Nancegollen.

The sound was heard at every place where the shock was felt, with the exception of Mabe, from which I have received no information on this point. At each it was compared to the low rumble of distant thunder, but at Helston the sound accompanying the second part of the shock was more like the discharge of distant artillery.

Earthquake of April 1st, 9.55 P.M.

This shock, though its intensity in no place exceeded 4, was the strongest of the series, and was much more widely observed than the preceding. The following account is based on 89 records from 56 different places. There are also 14 places close to the boundary of the disturbed area where the earthquake, so far as known, was not perceived.[1]

Isoseismal Lines and Disturbed Area.—The isoseismal 4 is 13 miles long, $7\frac{1}{2}$ miles broad, and contains 76 square miles. Its longer axis is directed E. 33° N. and W. 33° S. The isoseismal 3, which forms the boundary of the disturbed area, is 19 miles long, 12 miles broad, and 175 square miles in area, its longer axis running E. 32° N. and W. 32° S. The distance between the isoseismals is 1·7 miles on the north-western side and 2·7 miles on the south-eastern side. The centre of the isoseismal 4 is 2 miles east of Wendron. The centre of the disturbed area of the earthquake of March 29th lies almost exactly on the longer axis of the isoseismal 4, and at about a mile on the south-western side from the centre of this curve.

The forms and relative positions of the isoseismal lines enable us to determine the direction and hade of the originating fault. The average direction of the fault-line must be approximately parallel to the longer axes of the isoseismals, and therefore cannot differ much from E. 33° N. and W. 33° S. The hade of the fault must be to the south-east, as is shown by the greater distance between the isoseismals in that direction than in the opposite one. The exact position of the

[1] With the exception of one curve already mentioned, the accompanying map relates entirely to this earthquake.

fault-line cannot be ascertained from the seismic evidence: it must lie on the north-western side of the centre of the isoseismal 4. A line drawn through Wendron in the direction mentioned above would agree with all the phenomena known to me; though one lying between limits of $\frac{1}{2}$ mile to the south-east and 1 mile or so to the north-west of this line would be equally suitable.

Nature of the Shock.—Over a great part of the disturbed area the nature of the shock was nearly uniform, and the following account from Constantine may therefore be regarded as characteristic:—Two shocks, each lasting about 5 seconds, with an interval of about 15 seconds between them, the second being the stronger; in both, the intensity gradually increased and then died away, being greatest near the middle. The sound resembled thunder, and overlapped the shock by about 3 seconds at both ends; during the shock it appeared to be underneath the house, and was then much louder and sharper.

The most important feature is, no doubt, the double series of vibrations. Two distinct shocks were recorded at 25 places: at 9 of these each shock was accompanied by sound; at 12 others the sound was heard, but, as in the account quoted above, the double character is not recorded; while in the remaining 4 no mention is made of any sound being heard. Besides these, there were 6 other places where two distinct sounds were heard while no shock was felt, and 1 where two sounds were heard without any reference being made to the shock.

With regard to the relative intensity of the two parts of the shock, there can be little doubt that the second was everywhere the stronger. At Mawnan, Mylor, and Tolvan Cross the second shock was the stronger, and was accompanied by the louder noise; the second shock was the stronger at Constantine, Falmouth, Helston, Penryn, and Ponsanooth; and the second sound the louder at Godolphin Cross, Mawnan Smith, and Porthleven. The only exception to this statement occurs in the record from Rinsey, where the first sound is said to have been louder than the second; but as in other earthquakes there is always some variability in the evidence on this point, it is not unlikely that this exception is due to some misunderstanding.

The estimates of the interval between the two parts of the shock, as usual, differ rather widely, ranging from some seconds to 2 or 3 minutes, the average of 20 estimates being a little more than 1 minute. Even supposing this to be much in excess of the true value, it is evident that the first part must have been felt all over its disturbed area before the occurrence of the second at the focus.

The boundary of the area within which the double shock was felt is represented on the map (p. 2) by a broken line. It is 15 miles in length, 10 miles in breadth, and includes an area of 116 square miles. Its longer axis is directed E. 25° N. and W. 25° S., and is therefore nearly parallel to the axes of the isoseismal lines. The centre of the

curve is 0·8 mile N. 35° E. of the centre of the isoseismal 4, and the distance between these two curves is 1·5 miles on the north-western side and 0·8 mile on the south-eastern. It is thus evident that the boundary of the double-shock area does not coincide with an isoseismal line corresponding to any value between 4 and 3: in other words, that the foci of the two parts of the shock were not coincident. As the area in question is that over which the weaker of the two parts was felt, it corresponds therefore to the disturbed area of the first part of the shock, while the isoseismal 3 bounds the disturbed area of the second part.

Sound-phenomena.—The sound was heard by 81 observers at 51 different places, at 11 of which, however, no shock was felt. From 5 places where the shock was felt I have no record of the sound, but I think that the omission is accidental and due to the brevity of the account. It is clear, at any rate, not only that the sound-area included the whole of the disturbed area, but that it even overlapped it towards the south-west, north, and north-east: for the sound was heard by one observer at Kenneggy, by two at Baldhu, and by several persons at Tregothnan, the first two of which localities lie about 1 mile and the third about 2 miles from the boundary of the disturbed area. As the sound-vibrations in these cases would come chiefly from the upper margin of the focus, this overlapping confirms the inference that the hade of the fault is to the south-east.

Near the central part of the sound-area the sound was very loud, and was a far more striking feature than the shock. At Mabe one observer, who did not immediately recognize its seismic character, remarked that it was the loudest thunder that she had ever heard. Special reference to the loudness of the sound is made at 6 other places (namely, Bosvathick, Constantine, Gweek, Ponsanooth, Trannack, and Trewardrevah) in such terms as 'very near thunder,' 'a very heavy peal of thunder,' or 'a very loud explosion.' The intensity of the sound, however, diminished very rapidly with the increasing distance from the epicentre; for at 14 other places, all but two lying between the isoseismals 4 and 3, the sound is compared to distant thunder, distant gun-firing, or to wind. The inner dotted line on the map (p. 2) represents a line of equal sound-intensity, separating the places where the sound was loud from those where it was distinctly fainter. While it almost touches the isoseismal 4 on the north-western side, it does not reach so far as this curve in the opposite direction by nearly a mile, and it is thus approximately concentric with the boundary of the double-shock area and also with that of the sound-area. From the very rapid decline in the intensity of the sound compared with that of the shock, we may infer that the chief origin of the sound was not so deep as that of the more prominent vibrations; while the north-westerly shift of the line of equal sound-intensity with reference to the isoseismal 4 implies again that the hade of the originating fault is to the south-east.

The sound was of the ordinary deep character, not much above

the lower limit of audibility. All the common types of earthquake-sound were referred to, but a rather unusual preference is given to those of medium duration, 37 per cent. of the comparisons being to thunder, 25 to passing traction-engines, waggons, or trains, 24 to explosions or the firing of guns, 6 to wind, 2 to the fall of heavy bodies, 2 to the fall of a load of stones, while 4 per cent. are of a miscellaneous kind.

The time-relations of the sound and shock were those which are generally observed in a small earthquake. The beginning of the sound either preceded or coincided with that of the shock; their epochs of maximum intensity coincided; and the end of the sound either followed or coincided with that of the shock. Thus the duration of the sound was in all parts either equal to or greater than that of the shock; whence it follows either that the movements which gave rise to the sound-vibrations lasted longer than those which produced the shock, or else that the area from which the sound-vibrations proceeded was of greater linear dimensions than that from which the more prominent vibrations came, and extended beyond it at both ends. The latter alternative seems the more probable; in other words, the sounds heard before and after the shock came from the lateral margins of the focus.

Earthquake of April 2nd, about 3 P.M.

This was the slightest shock of the series, the intensity being apparently less than 4. I have only four undoubted records, coming from Mabe, Mawnan Smith, and Trewardrevah. A weak tremor was felt at each place, accompanied by a noise like distant thunder. So far as can be judged from the limited number of records, the epicentre appears to have undergone a further easterly displacement by about 2 miles.

Origin of the Earthquakes.

On the Geological Survey map of the disturbed area, very few faults are marked, and there is none that will agree even approximately with the conditions implied by the seismic evidence. There is, however, no contradiction between these conditions and the known geological structure of the district. To the south, in the neighbourhood of Mullion, the strike of the beds is parallel to the axes of the isoseismal lines, and there is a thrust-plane in the same direction which hades towards the south-east.[1] Near the epicentre itself the general strike of the lodes is about west-south-west, and several elvan-courses are parallel, or nearly so, to the isoseismal axes. One of these, copied from the Geological Survey map, is shown on the earthquake-map (p. 2). In position it satisfies the seismic conditions, and if the surface is faulted and hades to the south-east it is quite possible that a series of slips along it may have given rise to the earthquakes here considered.

[1] I am indebted to Prof. Lapworth for this information.

There can be little doubt that the earthquakes of March 29th and April 1st were connected with one and the same fault, for their isoseismal axes are parallel, and the line joining their centres is nearly parallel to these axes. Proximity in time of occurrence and disturbed area render probable a similar connexion for the third shock; for it is more likely that the change of stress brought about by such comparatively small movements should precipitate a slip in the same fault than in another fault of the same system. Assuming this to be the case, we see that the areas of successive slips were subject to a continual easterly advance along the fault.

Judging from the dimensions of the disturbed area, the focus of the first shock cannot have been much more than a mile in length, its centre lying beneath a point a short distance N. 33° W. of the centre of the disturbed area. The focus of the second shock was probably not less than 5, and not more than 7, miles long, its centre being about 1 mile E. 33° N. of the former. It must, therefore, have included the focus of the first earthquake. The position and magnitude of the third focus are indeterminate; but its length must have been very short, and, as it lay about 2 miles from the second centre, it must also have been included within the second focus, unless it was situated at a different level of the fault-surface.

Besides the focal transference along the strike of the fault-surface, there is also evidence of translation in the direction of its dip. Each of the first two earthquakes consisted of a double series of vibrations. Nothing can be learned from the double series on March 29th, except that there must have been two separate slips; but with regard to that on April 1st the evidence is unusually clear. Corresponding to each series of vibrations there was a distinct focus, that of the earlier shock being at the higher level.

Discussion.

Prof. Sollas welcomed this valuable addition to our knowledge of the connexion between faults and earthquakes. The Author had no doubt shown a wise reticence in abstaining from any expression of opinion as to the actual depth of the foci below the ground. The speaker could not help thinking that all earthquakes which are produced by the bumping of the country as it falls along a surface of faulting must originate at comparatively slight depths, not greater probably than 5 miles. When a depth of 30 miles has been assigned to the position of the focus, either the disturbance had some other cause than faulting, or inferences resting on the presumed angle of emergence of the wave at different points of observation were mistaken. The refraction of the wave as it passed from layers of the earth's crust of greater to those of less elasticity would of itself lead to an exaggerated estimate of the depth of the focus.

Prof. Milne and Mr. Teall also spoke.

2. Note *on* Drift-gravels *at* West Wickham (Kent). By George Clinch, Esq., F.G.S. (Read December 6th, 1899.)

There are two deposits of Drift-gravel at West Wickham upon which I propose to offer a few remarks. The first occupies the bottom of a valley which winds round the southern and western sides of Hayes Common and thence to Bromley. This is shown on the Geological Survey map, but there it appears that the Drift-gravel terminates somewhat abruptly near Keston. The valley itself, however, runs much farther south, extending to the North Downs near Tatsfield and roughly coinciding with the direction of the boundary-line between Kent and Surrey, but following a course varying from 2 miles to ½ mile east of that boundary.

A fairly good section of the gravel in the bottom of this valley may be found in a pit at Gates Green, a point near the junction of the three parishes of West Wickham, Hayes, and Keston. The beds exposed consist of rolled flints, fragments of Chalk, and bands of sand containing minute fragments of flint and portions of Chalk-fossils, including a large proportion of foraminifera. The beds also contain a few rolled fragments of ferruginous sandstone, probably derived from the Lower Greensand. The character of these beds is precisely what might be expected from the destruction of Chalk-beds. The fragments from the Lower Greensand also go to show that these gravels have a definite, although perhaps not direct, relation to the forces which excavated and denuded the Wealden area. The bands of sand indicate, I would submit, periods of comparative tranquillity during which the finer materials subsided.

The second deposit of Drift-gravel occupies portions of the sides and bottom of a short valley which branches off at right angles from the Gates Green Valley.

The Palæolithic implements and flakes exhibited on the occasion of reading this paper were found by me at West Wickham in the year 1880 and during four or five subsequent years. They are of considerable geological interest, inasmuch as they establish the fact, not, I believe, previously recorded, of the existence of Drift-gravels in certain valleys about a mile to the south of Hayes Common, but not so marked on the Geological Survey map. The implements themselves present one or two noteworthy features :—

(i) Many examples have lost their pointed ends, and bear other indications of having been much worn by use.

(ii) The result of Drift-wear is well shown upon a large proportion of specimens in the modified angles, and a general appearance of smoothness and roundness.

(iii) A few are entirely unworn by Drift-action, and retain all the ridges and angles which they received when they were chipped into shape.

(iv) Some of the implements, particularly the larger examples,

have been much bruised and crushed on the more prominent points by local influences, such as the ploughshare and the broad waggon-wheels employed by the farmer. It has been supposed by some that this bruised condition of the implements is due to excessive Drift-action, but I think it much more probable that it has been produced by the implements of husbandry.

(v) Most of the specimens have a superficial colouring varying from a pale straw colour to a rich ochreous-brown. It is, I believe, generally assumed that this colouring arises from the bed of clay in which the flints have been deposited for so long, but I am not quite convinced that this is the only, or even the chief, cause of the ochreous staining. Flint contains much iron, and one is tempted to enquire whether the staining may not be the result of oxidation of that metal liberated in the process of partial decomposition of the flint. The following seem to be the chief evidences that the Drift-implements have received their ochreous colour from some chemical change in themselves rather than from their environment:—

1. The ochreous colour is found only upon the surface or slightly below the surface of a flint which has undergone structural alteration.

2. It is not found to the same degree or in the same manner upon the original skin of the flint, portions of which remain upon the implements. The fact that this skin contains more lime and less iron than the flint proper would seem to account for this circumstance.

The proportion of iron in a Chalk-flint is variable. Klaproth, whose analysis is so frequently quoted, places 'oxide of iron' at ·25, but several chemists have assured me that the proportionate amount of protoxide of iron is often greater than this. Even were it not so, the proportion quoted by Klaproth would be sufficient to account for the deep stains which we find, as iron in a ferric state has very high colouring properties.

(vi) The association of much-worn implements, unworn implements, and flakes, cores, and waste chips in the same bed of Drift-gravel points to the fact that we have here a collection of material which has been brought from a great variety of places, and has undergone a great variety of conditions and changes.

Discussion.

Mr. A. M. Bell said that he was glad to see the Author's collection, as he had for many years gathered together a somewhat similar collection from near Limpsfield on the Greensand escarpment, 10 miles to the south of West Wickham. The Author's specimens had a *facies* of their own: they did not closely resemble those of Limpsfield, or of Ightham, or of Swanscombe. The speaker had classed the Limpsfield collection as belonging to three different periods: the earliest being of rare occurrence. On seeing the Author's collection, it struck him as strange that the latest period, well represented at

Limpsfield, seemed to be represented by only one specimen from West Wickham. Again, the Author's flint-implements had undergone much more wear than those of Limpsfield, which from the levels is natural, and he agreed with the Author that they had come from various sources and had travelled in some cases for great distances.

Mr. A. E. Salter stated that he had gone over the ground described by the Author, in company with Mr. Kennard, who (subsequently to Mr. Clinch's discoveries) had obtained a large number of Palæolithic implements and flakes from it. The deposit in which they occurred did not seem to be a definite bed of gravel, the specimens being found on the surface in company with a heterogeneous collection of materials, derived possibly from the London dust-carts. The valley-drift mentioned by the Author was quite distinct from that in which the implements occurred, and was, in the speaker's opinion, of later age.

The President and Mr. E. A. Martin also spoke.

The Author, in reply to Mr. Salter, pointed out that although no section, in the accepted sense of the term, existed in the second bed of gravel described, the effect of long-continued cultivation of the land had been to expose, in places on each side of the valley, undisturbed Drift-gravel. It was also pointed out that the implements bear evidences of Drift-wear, and have unquestionably formed part of a spread of Drift-gravel, although they were found upon the surface of arable land, and not *in situ* in their bed of gravel.

3. *On some* Effects *of* Earth-movement *on the* Carboniferous Volcanic Rocks *of the* Isle of Man. By G. W. Lamplugh, Esq., F.G.S. (Read December 20th, 1899.)

[Communicated by permission of the Director-General of H.M. Geological Survey.]

I. Introduction.

In a paper brought before this Society four years ago by Prof. W. W. Watts and myself, attention was drawn to some peculiar effects of earth-movement on the older Palæozoic rocks of the Isle of Man.[1] These rocks, constituting the Manx Slate Series, are unconformably overlain by Carboniferous strata in the south of the island, and from the manner in which the Carboniferous Basement Conglomerate evenly overspreads the denuded edges of the folded, cleaved, and crushed slate-series, it is certain that the movements which so profoundly modified the slates were of pre-Carboniferous age. This evidence led me at first to suppose that the region had undergone very little disturbance in later times, and further evidence tending to the same conclusion seemed to be afforded by the fact that the Carboniferous-Limestone outcrop in the south of the island, though traversed by numerous minor dislocations and undulations, nearly always presents a low dip and shows no readily recognizable indication of exceptional disturbance.[2]

Before completing the mapping of the island in 1897, however, I had occasion to re-examine the magnificent coast-section in the Carboniferous Volcanic Series between Castletown Bay and Poolvash (Poyll Vaaish) with the hope of clearing up some outstanding difficulties in regard to the relations of the limestone to these volcanic rocks which several previous examinations had failed to elucidate, and, being favoured by exceptionally low spring-tides, I then discovered evidence which threw new light upon this point. Both at the eastern and at the western extremities of the volcanic outcrop, this evidence indicated that the strata had undergone deformation of an extraordinary type subsequent to their deposition, and that many of their complex structures, hitherto supposed to be essentially due to the eruptive outburst, were, in fact, superinduced structures due to earth-movement. Two further re-examinations of the critical sections which I have made under similar circumstances during the present year, on the first visit accompanied by Dr. Wheelton Hind, Mr. J. A. Howe, and my colleague Mr. Walcot Gibson, and on the second by the Director-General of the Survey, have confirmed me in the conclusions reached in 1897. As my official memoir on the island, containing a detailed description of the sections, is

[1] 'The Crush-conglomerates of the Isle of Man' Quart. Journ. Geol. Soc. vol. li (1895) pp. 563–97.
[2] *Ibid.* p. 585.

in an advanced stage of preparation, my present object is briefly to call attention to such structures as appear to be of more than local interest, leaving the full statement of the local evidence for the forthcoming Survey memoir.

The general characters of the exposure are already well known to British geologists. They were described early in the present century by Berger,[1] Macculloch,[2] and Henslow,[3] and in greater detail in more recent years by Cumming,[4] Horne,[5] Clifton Ward,[6] Bernard Hobson,[7] and Sir Archibald Geikie.[8] The coast-line was mapped on the 25-inch scale in 1892 by Mr. A. Strahan and myself, and it was at that time that those anomalous features were observed, which rendered necessary my later search for further evidence.

II. Position and Extent of the Volcanic Outcrop.

The volcanic rocks lie at the southern margin of a little tract of Carboniferous Limestone 7 or 8 square miles in extent, and occupy a broad craggy foreshore for a distance of about $1\frac{1}{4}$ miles, from Scarlet Point on the south-east to Poolvash (Poyll Vaaish) Inlet on the north-west, but nowhere reach for more than 200 or 300 yards inland. The eastern portion of this belt consists of a chaotic mass of coarse and fine fragmental volcanic material, traversed by ridges of basaltic rock (the 'augite-porphyrite' of Hobson) which are dyke-like in their mode of occurrence, but usually possess the vesicular flow-structure and other characters of lavas. Entangled among these rocks are many isolated patches of dark limestone, ranging in size from blocks 1 or 2 feet in diameter to strips several yards long and several feet thick, in which the original flaggy bedding is still preserved. In the western part of the outcrop, the volcanic material is made up almost entirely of tuff, often fine in texture and calcareous in composition, in places exhibiting excellent bedding and containing a few marine fossils. Here, also, crumpled strips and dome-shaped lenticles of limestone are sporadically distributed, increasing in size and frequency towards the western junction of the tuff with the limestone.

[1] 'Mineralogical Account of the Isle of Man' Trans. Geol. Soc. vol. ii (1814) p. 45.

[2] 'A Description of the Western Islands of Scotland, including the Isle of Man' vol. ii (1819) pp. 570–71.

[3] 'Supplementary Observations to Dr. Berger's Account of the Isle of Man' Trans. Geol. Soc. vol. v (1821) pp. 495–96.

[4] 'On the Geology of the Isle of Man' Quart. Journ. Geol. Soc. vol. ii (1846) pp. 322–23; see also his 'Isle of Man; its History, etc.' London, 1848, pp. 129 *et seqq.*

[5] 'A Sketch of the Geology of the Isle of Man' Trans. Edinb. Geol. Soc. vol. ii (1874) pp. 335 *et seqq.*

[6] 'Notes on the Geology of the Isle of Man' Geol. Mag. 1880, p. 5.

[7] 'On the Igneous Rocks of the South of the Isle of Man' Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 432; reprinted with some additions and corrections in 'Yn Lioar Manninagh' vol. i, pt. x (1892) p. 337.

[8] 'Ancient Volcanoes of Great Britain' vol. ii (1897) pp. 22–32.

III. Relation of the Carboniferous Limestone to the Volcanic Series.

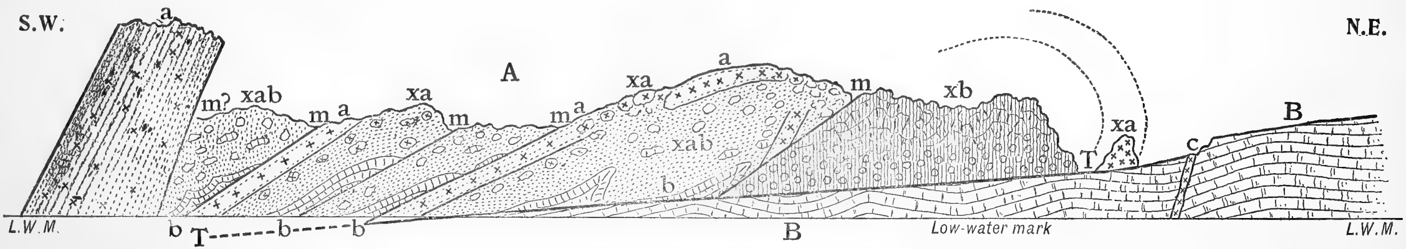
These patches of limestone among the finer ash have hitherto been held to be truly interbedded, and to denote intervals of quiescence in the volcano during which calcareous sediment accumulated in hollows of the surface of the submarine tuff. The similar patches among the basaltic rocks and coarse agglomerates at Scarlet Point have been, however, generally recognized as out of place, and have been usually supposed to owe their position to some peculiar effect of the eruptive activity which is considered to have had its focus in this quarter.

But in all the sections alike these strips of limestone have undergone disturbance of a singular type, for which no adequate explanation seemed forthcoming, while a serious difficulty in considering them to have accumulated in hollows of a sea-floor of pumiceous ash was that in most cases they are free from ashy admixture. And it is now my opinion that all the larger of these lenticles, as well as most of the smaller blocks of dark argillaceous limestone among the coarse agglomerate, have been torn up from the underlying limestone-floor during a sliding forward or over-thrusting of the volcanic series upon this floor. The only calcareous deposits which I can definitely recognize as having been originally interbedded with the Volcanic Series are certain thin bands of ashy limestone associated with finely-laminated, and sometimes nodular, calcareous tuff in the middle portion of the outcrop, between Cromwell's Walk and Close-ny-Chollagh Point. These beds have been implicated in the general disruption brought about by the overthrusting, but are seen here and there in large patches in a comparatively unbroken condition. The grounds for my conclusions are contained in the following descriptions of three typical sections, of which the first lies at the eastern extremity of the volcanic out-crop, the second at its western extremity, and the third in the midst of the series.

IV. The Section at Scarlet Point. (Fig. 1, p. 14.)

When the section on the eastern side of Scarlet Point, south of the little gully which separates the broad undulating scars of the dark flaggy Lower or Castletown Limestone from the jagged mass of the volcanic rocks, was examined at the lowest tides, it was found that the flaggy strata did not terminate, as previously supposed, at the gully, but were prolonged beneath a confused pile of massive limestone and limestone-breccia which occurs in close association with the volcanic rocks on the southern side. The edges of the rolling limestone-flags were truncated by a plane dipping gently southward, upon which rested massive recemented limestone-breccia. The dark stratified limestone was traceable as a low-water reef almost up to the northern front of the great basalt-pinnacle known as the Stack of Scarlet, encircling the base of the high crags of vesicular basalt and coarse agglomerate which

Fig. 1.—*Diagrammatic section across Scarlet Point west of the Stack, showing the probable relation of the Volcanic Series to the Carboniferous Limestone.*



[Length of section = about 150 yards; maximum height = about 40 feet.]

A = **Volcanic Series**: ash, agglomerate, and vesicular basalt; a = Vesicular basalt.
B = **Lower Carboniferous Limestone**; b = Strips of the same dragged up into the Volcanic Series.
xa = Coarse agglomerate: large blocks of vesicular basalt in an ashy matrix; xab = Similar agglomerate, with some limestone-blocks.
xb = Large mass of limestone, much contorted and brecciated; c = Olivine-dolerite (Tertiary ?) dyke, possibly filling a line of fault.
T = Major thrust-plane; m = Minor thrust-plane.

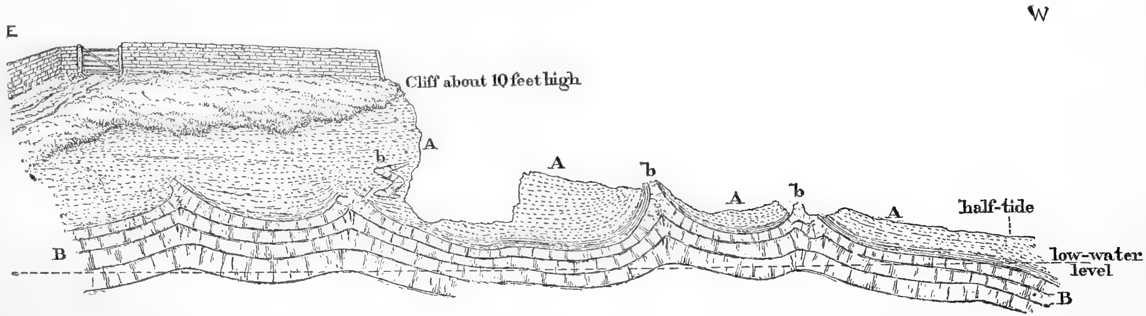
abut upon the above-mentioned pile of brecciated limestone; and at three or four places long narrow strips of the dark limestone were found to shoot steeply upward and become most singularly wedged in between the component blocks of the Volcanic Series, while smaller shreds of similar limestone were completely isolated among the coarse agglomerate which borders the Stack. In these strips, indications of sliding and disturbance were everywhere visible, and the outer surfaces were indurated into chert-like material. It is difficult to give the evidence its full weight without stating all the details, but I think that it can be proved that these complexities have not been caused by the volcanic outburst, but have been brought about at a later date by the differential movement of segments of the eruptive rocks upon their original floor of limestone. My interpretation of the phenomena is embodied in fig. 1 (p. 14).

V. The Section at Poolvash. (Fig. 2, p. 16.)

At Poolvash the junction of the tuffs with the limestone may be traced across the foreshore, in a direction slightly oblique to the coast-line, for nearly $\frac{1}{2}$ mile, presenting many variations in detail, but everywhere exhibiting indications of relative displacement of the overlying to the underlying strata. For the greater part of this distance the ash rests upon the black argillaceous limestone-flags ('*Posidonomya*-beds' of Cumming), which form the uppermost member of the Limestone Series in the south of the island, but near the western end of the outcrop, opposite Poolvash Farmstead, it apparently comes at one place into juxtaposition with a somewhat lower horizon (namely, the 'Poolvash Limestone' of Cumming). There is everywhere at the base of the ash a few inches of crushed material possessing a platy structure, usually consisting of decomposed ash, but sometimes of shattered black shale like that intercalated with the limestone-flags. The surface of the limestone beneath this plane is characterized by cherty induration and by the presence of much pyrites, while bright slickensides are occasionally seen along fractures passing obliquely downward from the junction. Sharp-cut planes of induration overlain by platy crushed material are also present in the body of the ash above the junction.

The most instructive section occurs on the south-eastern side of the bay, under the remains of an ancient earthen fort, where the limestone first emerges from beneath the tuff. At this point the smooth limestone-flags have been rucked up into shallow folds which, in a few feet, die out downward into gentle dome-like undulations, but increase rapidly in steepness upward, and at the junction break into sharp crests which shoot up into the ash almost like intrusive dykes, and are then bent over towards the north, as shown in fig. 2 (p. 16). These structures have been so admirably dissected out by marine action that we may trace the limestone-anticlines step by step along the foreshore in the direction of their axes (at right angles to the figured section); and, as the folds have on the

Fig. 2.—*Section across the foreshore on the northern side of Close-ny-Chollagh Point, Poolvash, showing the rucking up of the Upper Limestone beneath the Volcanic Series.*



[Length of section = about 120 yards.]

A = Volcanic ash of medium texture, with contorted strips and fragments of cherty limestone (b).

B = Dark flaggy limestone ('*Posidonomya*-beds'); platy, indurated, and pyritous in the uppermost layer, with signs of shearing (=thrust-plane); rucked up into short domes, the crests of which are in places pinched into the ash and brecciated.

whole a gentle easterly pitch, we pass eastward from the horizon at which the limestone-flags are simply undulating to the place where, at the foot of the low cliff, the sharp crests pass up into the ash and present the appearance in cross-section of being intercalated with it. Between the crests, small ragged strips of limestone, altered around the margins into chert, are crumpled into fantastic shapes and entangled among the tuff. All these effects seem necessarily to imply a general movement and re-arrangement of the ash in its relation to its limestone-floor, and I see no alternative to this conclusion.

VI. Internal Structure of the Volcanic Series.

Much that was previously inexplicable in the internal structure of the volcanic rocks became clear to me when the character of the displacement at the base of the series had once been grasped. With this foreknowledge I found everywhere indications of local displacement and readjustment; the isolated patches of limestone were seen to present features compatible with their having been torn up from the underlying floor, like the strips at Scarlet and Poolvash: the bands of vesicular basalt were observed to have been bent into curves and often shattered into fragments; and the finely-laminated tuffs with calcareous bands were found to have suffered fracture and step-faulting every few feet, or sometimes inches, and even in this condition to occur only in limited blocks, breaking off all round into a confused mass in which the laminated structure was suddenly blotted out and replaced by a rude streaky arrangement in the otherwise structureless ash.

In the forthcoming Survey memoir I hope to describe and illustrate these features in full detail, and meanwhile must be content to state my conclusions in more or less general terms. The effects of the movement are always intensified towards the limestone-junctions and again, to a still greater degree, in the vicinity of the masses of basalt. The laminated structure is rarely visible in the ash except in places most remote from these, and is therefore best developed in the middle portion of the outcrop, between Cromwell's Walk and Close-ny-Chollagh Point. The accompanying section (fig. 3, p. 18) of the foreshore about 200 yards south of the last-mentioned place represents what I believe to be the least disturbed portion of the whole series. At the base of this section, the fine tuff containing thin intercalations of cherty limestone is regularly and evenly stratified, but is shaved off at a bedding-plane by a slide which crumples and tears up the overlying strata bed by bed, producing a confused agglomerate of ash and cherty ashy limestone in the upper part of the section.

The massive ridges of vesicular basalt, which occur principally between Scarlet Point and Cromwell's Walk, are persistently accompanied by coarse agglomerate, consisting of large subangular blocks of the basalt (and sometimes also of cherty limestone) in a streaky matrix of ash. While acknowledging the difficulty in

distinguishing between original and superinduced features in rocks of this character, I am inclined to regard this agglomerate as derived, at least in part, from the disruption of portions of the adjacent basalt during the movements. Some degree of smashing must certainly have taken place in these basalts. Thus at Cromwell's Walk the dyke-like mass, 15 to 20 feet thick, has had a segment sliced off and thrust forward among the agglomerate so that the beautifully distinct flow-lines of vesicles are sharply truncated along the fractured edge,[1] and the same edge displays a succession of gaps and notches, now filled in with the enveloping ash, from which blocks have evidently been broken and presumably are now to be found in the adjacent agglomerate. Fractures of the same kind are sometimes found to cut up the thinner bands of basalt in such a manner that it is impossible to fix the point where the lava ends and the agglomerate begins. Moreover, the agglomerate is full of limestone-blocks in the vicinity of the included strips of limestone, and of vesicular basalt in the neighbourhood of the basalt-masses; and though the two kinds of blocks are also commingled, their

Fig. 3.—*Section across the foreshore, 250 yards south of Close-ny-Chollagh Point, showing the sliding forward and breaking up of bedded calcareous ash and impure limestone, with unbroken beds below.*

[Length of section = about 100 yards.]

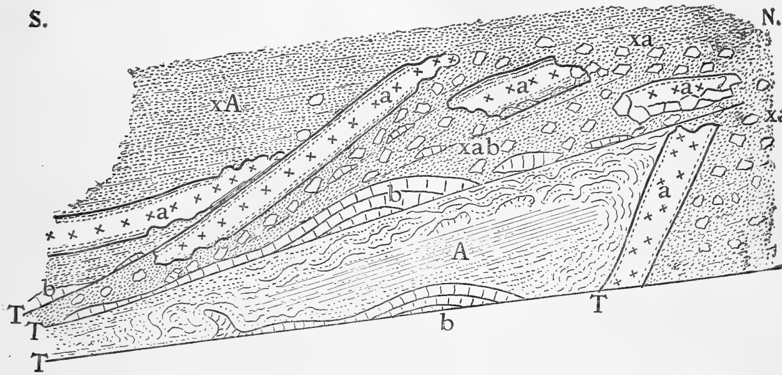
A = Evenly-bedded fine calcareous ash and thin cherty impure limestone-bands (6 feet seen).
b = Ash and limestone, like that below, crumpled, broken, and confused.
m = Small thrust-plane separating the broken from the unbroken beds; shifting to higher bands in going eastward. The ash is indurated for 2 or 3 inches beneath his plane.

[1] As described and figured by Sir Archibald Geikie in his 'Ancient Volcanoes of Great Britain' vol. ii (1897) p. 31.

relative abundance is clearly influenced by the character of the masses in their proximity.

The following diagram has been prepared to illustrate my view in regard to these structures, and will also serve to elucidate the subsequent paragraphs.

Fig. 4.—*Diagram illustrating the supposed general result of earth-movement in the Volcanic Series east of Cromwell's Walk: a disrupted anticline of rigid lava pushed northward along a thrust-plane.*



A = Volcanic ash, much disturbed, but showing traces of original bedding.
xA = Rearranged volcanic ash; a = Vesicular basalt; b = Strips of limestone carried up along thrust-planes.
xa = Coarse agglomerate of vesicular basalt-blocks in an ashy matrix; xab = The same, with some limestone-blocks. TT = Thrust-planes.

If my reading be correct, it follows that all the anomalous phenomena exhibited in the outcrop of the Manx Carboniferous volcanic rocks at present above sea-level may be explained as the result of earth-movement upon a belt of strata consisting of limestone passing up into stratified submarine tuff, with interbedded lava-flows and possibly sills or dykes in the eastern part of the exposure.

VII. General Character of the Disturbances.

Although my previous work among the Manx Slates had enlightened me as to the potentiality of earth-movement in disorganizing original stratification, I was not prepared to find that such results could occur with so little modification of the rock-substance as presents itself in the Volcanic Series.

In the crush-conglomerate of the Slates, the shearing has been intense; the rock-fragments have been dragged out into phacoids; strain-slip cleavage has been magnificently developed in every part of the mass; and in tracts adjacent to the belts of disruption, though the original bedding may still persist, the rocks are packed

into closed folds and are sheared in every part. It is true I found indications that the material was further sheared after it was brecciated,[1] but I regarded the two structures as practically inseparable, and both seemed to have been produced under a superincumbent weight sufficiently great to cause movement analogous to fluxion throughout the mass.

In the Manx Volcanic Series, however, the rocks have been packed together and shattered in a well-defined localized belt, without any perceptible change of intimate structure, with little or no flattening of the fragments, and without any marked effect upon the earlier Carboniferous strata outside this belt. We might say that they have locally undergone 'brecciation-without-crushing,' in contradistinction from the 'brecciation-with-crushing' of the Slates. Moreover, the disturbances seem to have been limited in the horizontal as well as in the vertical plane, and to have been almost confined to strata of a particular lithological type. It is probable that the movement did not even extend down to the base of the limestone, which is likely to be at a depth of not much more than 200 feet below the Volcanic Series in this locality; and the apparent freedom with which the disturbed rocks have burst upward indicates a comparatively superficial plane for the belt of disturbance.[2] In studying the sections, one has indeed been led to speculate upon the possibility of the effects having been produced by the slipping outward of the margin of a steep submarine volcanic cone of which we might see only the edge in these exposures, or by some other form of local movement accompanying the later stages of the eruptive period. No such explanation, however, seems sufficient, and I think that the phenomena are more probably part of the wider system of disturbances which has affected the Lower Carboniferous rocks of the Isle of Man in common with rocks of the same age in the east of Ireland on the one side, and in the country south of the Lake District on the other.

However that may be, it is clear that the factor of prime importance in determining the extraordinary features of these sections has been the varying degree of resistance to lateral pressure offered by this heterogeneous sequence. If the whole series had been composed of limestone, it is easy to believe that the requisite degree of contraction would have been obtained by a simple system of folding. But the rigid lava-flows and sills interbedded among semi-coherent ash under no great weight of superincumbent material have proved incompressible, and when tilted up by earth-creep have snapped into huge segments and ploughed into the surrounding tuffs, which have been rearranged and repacked around them. The unequal pressures thus brought to bear upon the floor of limestone have rucked up that material into

[1] Quart. Journ. Geol. Soc. vol. li (1895) p. 585.

[2] It may be remarked that Prof. C. R. Van Hise, in discussing 'autoclastic' structures in general, states that brecciation is probably confined to a comparatively moderate depth in the earth's crust; see his 'Principles of North American Pre-Cambrian Geology' 16th Ann. Rep. U.S. Geol. Surv. pt. i (1896) pp. 679–80.

incipient folds, the crests of which have been pinched off and carried forward along the minor thrust-planes between separate blocks of the overlying disorganized mass.

Essentially the whole structure is a small-scale reproduction of that well-known feature in mountain-building—the broken and overthrust anticline. The peculiarity of the present instance is that the development of the structure appears to have been determined mainly by the lithological contrast of the rocks at a strictly local focus. It is highly probable that local disturbances of this type will be found wherever the same conditions prevail, though such opportunity for demonstrating them as is afforded by the magnificent coast-exposure of the Isle of Man must necessarily be rare. I may be permitted to state that four years ago, when seeking for structures analogous to the crush-conglomerates of the Manx Slate in the Lake District, my attention was directed by Mr. Marr and Mr. Harker to sections in the Borrowdale Volcanic Series under the Sty-Head Pass, where they had noticed brecciation of the bedded ash. On examining these sections I came to the conclusion that the structures were not of the type of which I was in search; but now, on reading my notes made at that time, I recognize features closely similar to those presented by the Manx Carboniferous bedded tuffs, though the mineral condition of the rocks is quite dissimilar. Again, when on a mission with the same object to the eastern coast of Ireland three years ago, I was shown by my colleague, Mr. McHenry, certain phenomena in the Silurian volcanic rocks of Portraine, attributed by him to earth-movement,[1] but not much resembling the crush-conglomerates with which I was then acquainted. These also I now find are analogous in some respects to structures in the Manx Carboniferous volcanics.

I should like to point out that the behaviour of the limestone in the sections which I have described affords striking confirmation of the view insisted upon by Mr. Marr in a paper recently brought before this Society,[2] as to the extraordinary facility with which this rock is moulded and squeezed into abnormal positions under earth-movement. In that paper Mr. Marr sought to explain the knoll-like structures in the limestone of the Craven district as having been caused by anticlinal overthrusting of a peculiar type, in some respects akin to that now described in the Manx volcanic rocks. In the discussion after the reading of the paper I referred to the presence of small knolls of limestone on the shore at Poolvash which I believed to be similar to those described by Mr. Marr. These I had previously held to be original structures, possibly due to the rapid consolidation of shell-banks and their subsequent erosion by currents.[3]

The Poolvash knolls lie just outside the present margin of the

[1] See 'Nature,' vol. liii (1896) p. 414.

[2] 'On Limestone-knolls in the Craven District of Yorkshire & Elsewhere Quart. Journ. Geol. Soc. vol. lv (1899) pp. 327–358.

[3] Brit. Assoc. 'Handbook to Liverpool & Neighbourhood' (1896) p. 174.

Volcanic Series and must once have been overlain by the tuff. They occur in a limestone which, I think, must have originally possessed a lenticular structure, but I should now admit that, whatever its original arrangement, the limestone at this point was implicated in the movements which have affected the volcanic rocks. It may be added, however, that on examining the Craven knolls during the past summer, I found less similarity between them and those of Poolvash than I had anticipated, and that I should now hesitate to regard the structures as identical.

VIII. Age of the Movement.

Much light as to the age of the movement has been obtained from the deep borings recently made in search of coal on the Drift-covered plain at the northern extremity of the island. These borings, collectively, after passing through Drift of exceptional thickness, penetrated a varied series of New Red rocks, consisting of Saliferous Marl, St. Bees' Sandstone, Lower Marl, and Brockram, directly comparable with deposits of the same age on the opposite Lancashire and Cumberland coast. These Red Rocks constitute a conformable and undisturbed sequence with a low regular dip, and rest on the uptilted edges of Lower Carboniferous strata having a high dip and showing signs of great compression and disturbance. It is usual to assign an Upper Permian age to the lower part of this New Red Series in Cumberland; and if this be correct, the Lower Carboniferous rocks of the island must have been affected by severe movement at an earlier date than Upper Permian; in any case it is clear that the disturbances were pre-Triassic. The Peel Sandstones and Conglomerates of the western coast of the island seem to have participated in these movements; and these rocks have usually, and I think rightly, been considered not newer than Lower Carboniferous, though a Permian age has recently been claimed for them.[1]

The movements which I have discussed may therefore be assigned to some period in the interval between Lower Carboniferous and Upper Permian times. They probably belong to a single epoch, and brought about a northward overthrust of the higher beds upon the lower in the south of the island. This direction is towards the central massif into which the Manx Slates had been compressed during an earlier cycle of earth-movement.

Discussion.

The President, after congratulating the Author on his paper, read the following extract from a letter that he had received from Sir Archibald Geikie, who was unable to be present:—

'Having been twice with Mr. Lamplugh over the ground which he describes, the second time quite recently, since his present views as to earth-movement were formed and matured, I am glad to bear my testimony to the exhaustive care which he has expended on the

[1] W. Boyd Dawkins, Trans. Manch. Geol. Soc. vol. xxii (1894) p 590 & vol. xxiii (1895) p. 147.

research. I agree with him on the main point—that there is conclusive evidence of considerable earth-movement since the deposition of the Carboniferous volcanic rocks at the southern end of the Isle of Man. He seems to me to have established this point beyond dispute. How far the tumultuous structures in some of the agglomerates should be attributed to the original volcanic conditions of accumulation, and how far to subsequent earth-movements, is a question on which there is room for difference of opinion. Possibly some of those structures which Mr. Lamplugh would regard as subsequent are among those which seem to me more probably original. We can hardly exaggerate the confusion of arrangement in the materials of many volcanic agglomerates. And when these materials come subsequently under the operation of movements of the terrestrial crust, it is obvious that the task of separating the one set of effects from the other becomes exceedingly difficult.'

Prof. C. Lapworth expressed his admiration of the clear and convincing way in which the Author had laid his most interesting results before the Society. It was most instructive to note how phenomena once regarded as depositional and of unquestionably contemporaneous origin, had shown themselves to be dynamic and of subsequent date. Although the Author and others still adhered to the view that the volcanic phenomena were of Carboniferous Limestone age, he felt himself that, as interpreted by the fold-theory of deformation, there was much to be said in favour of the view that they also were of subsequent date and of the age of the crust-movement. In great crust-movements the differential deformation and friction of the stratified masses moving on opposite sides of a plane of contrary movement gave origin to mechanical breccias, and caused the rolling-out of masses and fragments into ball-like forms. Igneous matter, making its way between the moving masses, may consolidate as sills where the pressure is great, and as amygdaloidal masses where the pressure is locally relieved. The presence of associated superheated waters, etc. would account for the dissolution of limestones, the formation of cherts, with included derivative fossils, and even for the simulation of natural bedding. As movement progressed intermittently, we should have the formation of subterranean agglomerates, tuffs, and breccias, which would be forced locally sometimes between bedding-planes, sometimes into dyke-like fissures. Where, finally, the impounded waters, gases, igneous matter, and mixed materials found an exit to the surface, a vent of escape for some of them would be formed. If vertical, it would be an ordinary pipe-vent or neck; if oblique, it might be mapped as a sheet of agglomerate, or a row of volcanic necks.

As respects the relationships of these Isle-of-Man structures to the Pennine knoll-reefs described by Mr. Marr, he had himself little or no doubt that both were primarily of dynamic origin. The axes of the great crust-folds recognizable in Britain and Western Europe were four in number—two primary (parallel to the lines of latitude and longitude), and two resultant (diagonal to these); while the 'swirl' or direction of the overcreep was left-handed, answering

to the ordinary cyclonic movements of the air in the northern hemisphere. These knoll-reefs of Mr. Marr (as well as the Poolvash thrust-planes), like the 'klippen' of the Vale of Eden, come into the proper position for overfolding and overthrusting. The exquisite preservation of the knoll-reef fossils is due to the fact that these 'reefs' are 'augen' on a gigantic scale, where pressure has been locally relieved and the fossils preserved in infiltrated carbonate of lime.

It is by no means unlikely that the knoll-reefs and the Isle-of-Man phenomena, as pointed out by recent observers, are both of the age of the 'Hercynian movement' of Suess; namely, that part of the Permo-Carboniferous period which we in Britain term 'Upper Coal Measures,' where igneous matter is frequent in the sediments, and we have probably the intrusion of the Whin Sill, the Shropshire and Midland basic rocks, etc.

Prof. Boyd Dawkins accepted the Author's view that the overthrust-faulting was, in part at least, later than the age of the intrusion of the volcanic rocks into the Carboniferous strata of the south of the Isle of Man. He further remarked that the overthrust-faulting in the Red Series of Peel, in the north-west of the island, considered by the Author to be basement Carboniferous, but taken by the speaker, from the included pebbles of Carboniferous Limestone and Yoredale rocks, to be Permian, proves that the overthrust took place after the deposition of the Permian.

The Rev. J. F. Blake thought that the attempt to explain all sorts of phenomena by 'earth-movement' might be carried too far, and some of the wilder flights of theory were in danger of sharing the fate of the 'Réseau pentagonal' of Elie de Beaumont. Such, for instance, was the theory of the limestone-knolls in the Craven district, which had he thought lately received its *coup de grâce* from Mr. Dakyns. With regard to the area described by the Author, if it is admitted that parts of the phenomena may be those of an agglomerate, there is no reason why 90 per cent. of them may not be. The diagrams shown appeared to indicate supposed movements in several convergent directions which would require explanation; and it seemed impossible that fragments sporadically placed and angular, as drawn, could be found between two approximate thrust-planes.

Mr. Strahan remarked on the difficulty of distinguishing the results of so energetic a volcanic outburst from those of subsequent earth-movements. After mapping the volcanic region, both he and the Author had been unable to explain some of the structures. Masses of lava had been obviously broken and shifted, and there were other indications of disturbance. For such phenomena the Author's hypothesis seemed to offer an adequate explanation, yet he could not fully accept the theory without hesitation. The Carboniferous rocks of the neighbourhood showed no signs of such powerful earth-movements as were claimed; on the contrary, they reposed tranquilly on the platform of older rocks near the region described, and it was only in the immediate neighbourhood of the

eruption that any signs of disturbance manifested themselves. The eruption, moreover, was one of exceptional energy and extent, far more so than the contemporaneous outbursts in Derbyshire and Somerset, nor could we judge of its full extent, for one margin only of the volcanic tract was visible above the sea. For these reasons he was still disposed to attribute some of the structures described to the tumult caused by the ejection of igneous material on the sea-bottom; but at the same time he congratulated the Author upon his presentation of an excellent working hypothesis.

Prof. Watts said that he had gone over the district described by the Author, and was struck by the fact that the Carboniferous limestones and tuffs both occurred in knolls and knobs apparently of precisely similar structure. If so much earth-movement had affected rocks subsequently to the Carboniferous period, great caution must be exercised in working out the structures of rocks of this date. He referred to the intrusive clastic sills which occur in the South of Ireland, at Berehaven and elsewhere.

The Author, in reply, acknowledged the difficulty in distinguishing between original and superinduced structures in rocks of this character, and said that he had not ventured to assign the exact proportion of the one to the other. But he claimed that the present position of the limestone-lenticles showed that there must have been great disruption and re-arrangement throughout the series. There seemed no reason to doubt that the greater part of the ash had been deposited in the sea. That the disturbance was so much more acute in the volcanic rocks than in the limestone was probably due to the heterogeneous composition of the former. The movement throughout seemed to have been approximately from south to north, and Prof. Blake's difficulty arose from the fact that the sections exhibited were not all at the same angle in regard to the movement. He was glad that Prof. Boyd Dawkins agreed that the Peel rocks had also been disturbed, and regretted that they should still hold different opinions as to the age of these rocks. He desired to thank Prof. Watts for having stimulated the further research which had led to the present results, by his friendly criticism when they were together in the field.

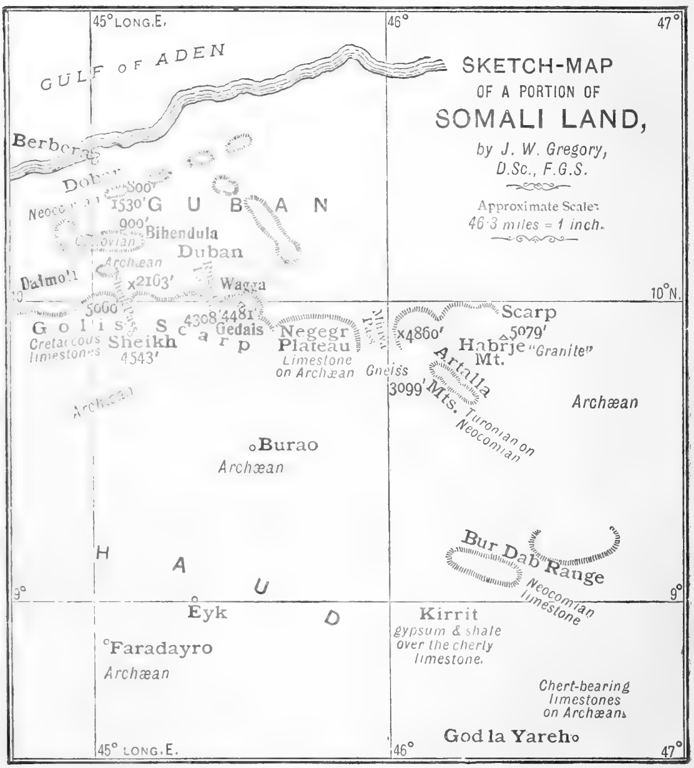
4. *On the* Geology *and* Fossil Corals *and* Echinids *of* Somaliland.

By J. W. Gregory, D.Sc., F.G.S. (Read December 6th, 1899.)

[Plates I & II.]

Contents.

Fig. 1.



I. Introduction.

British Somaliland consists of a high plateau, of which the northern scarp is separated from the Gulf of Aden by a belt of low hills and plains, known as the Guban. The southern plateau consists of a vast block of Archæan rocks, mainly gneiss and amphibolites, with intrusive pegmatite-dykes, and it is

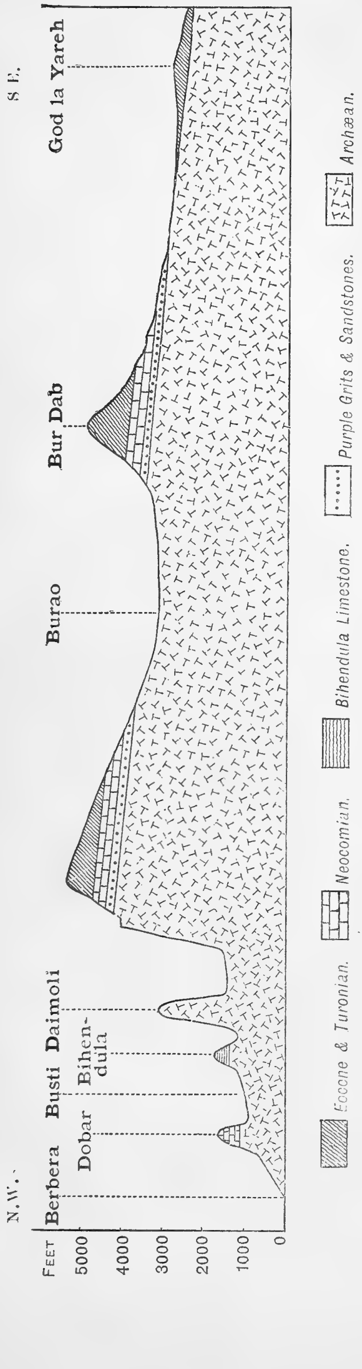


Fig. 2.—*Section across a portion of Somaliland, from the coast at Berbera to God-la-Yareh.*

capped by purple grits, red sandstones, and conglomerates. The more rugged peaks of the coastal belt are outliers of the Archæan plateau; but the main geological interest of this area is due to the occurrence in it of a series of limestones. That the limestones belong to more than one period was obvious from the earliest accounts of them. Thus M. de Rochebrune,[1] who in 1882 first described the Somali limestones, identified the fossils collected by Révoil in the Singeli country (lat. 11° N. & long. 49° E.) as Neocomian; and Miss Raisin,[2] who six years later gave an account of the specimens collected by Capt. King at Mount Eilo, south of Zeila (lat. 10° 30′ N. & long. 43° 35′ E.), suggested, on the evidence of the foraminifera, that the limestone at that locality was late Cretaceous or more probably Kainozoic.[3] The fossils described by M. de Rochebrune were obtained in Eastern Somaliland; the limestone described by Miss Raisin came from the western part of the Guban; while the Neocomian fossils described by Prof. Mayer-Eymar[3]

[1] A. T. de Rochebrune, 'Obs. géol. & pal. Région Çomalis' Mission Révoil, Faune & Flore des Pays Comalis, 1882 (pt. vii), 39 pp. & 4 pls.

[2] C. A. Raisin, 'Rock-specimens fr. Somaliland' Geol. Mag. 1888, p. 418.

[3] C. Mayer-Eymar, 'Neocom. Verst. Somali-Lands,' Vierteljahrsschr. naturf. Gesellsch. Zürich, vol. xxxviii (1893) pp. 249–65.

were collected by Prof. Keller on the south-western slopes of the Somali plateau, along the valley of the Faf, a tributary of the Webi Shebeli.

A geological collection made in the winter of 1894–95 by Mr. and Mrs. Lort Phillips, Miss Edith Cole, and Mr. G. P. V. Aylmer demonstrated the occurrence of two distinct limestones in the central area of the Guban, south of Berbera.[1] In the paper describing this collection, some suggestions were made as to points on which information would be especially useful; and in reply I have received some further collections which practically settle the three problems then mentioned as unsolved. The largest collection was made by Mr. and Mrs. Lort Phillips, Miss Gillett, and Mr. G. P. V. Aylmer in the Golis Mountains and in the coastal belt between the foot of the Golis scarp and the sea. Capt. E. T. Marshall has kindly sent me a supplementary collection of rocks from the Haud and of fossils from the raised beaches of the Maritime Plain. A collection of fossils from the limestones east of the Berbera district and some fossils from the high-level limestones has been made by Mr. F. B. Parkinson. To Mr. Aylmer I am greatly indebted for a carefully-prepared map of the Guban and of the watershed along part of the northern margin of the central plateau.

To all these travellers I must express my best thanks for their interesting collections, which throw light on three problems:—the distribution of the Archæan rocks; the age and sequence of the limestones; and the date of the foundering of the Aden Gulf.

II. The Archæan Series.

The Archæan rocks from the Haud and its northern outliers include gneiss, amphibolites, mica- and chlorite-schists, coarse quartz-orthoclase-pegmatites, etc. They belong to types familiar from the descriptions of the similar rocks from Socotra by Prof. Bonney[2] and from Western Somaliland by Miss Raisin.[3]

The principal varieties have been recorded from the area south of Berbera in my note of 1896 (*op. jam cit.*). It is therefore only necessary to give the following list of localities where the present collections have proved the occurrence of the Archæan Series:—

Localities.	*N. Lat.*		*E. Long.*		*District.*	*Altitudes in feet.*	
East of Gellakur ...	10°	5′	45°	15′	Uradu	...	Syenitic gneiss.
Foot of Rugga Pass	10	0	45	20	,,	...	Gneiss.
Top of Rugga Pass	10	0	45	20	Golis	4300	Gneiss and quartzite.
Upper Sheikh	9	55	45	10	,,	4543	Gneiss and chloritic schist.
Sok Soddah	9	47	45	20	,,	4308	Saussuritic gneiss and chloritic schist.

[1] See my 'Note on the Geol. of Somaliland,' Geol. Mag. 1896, pp. 289–94.

[2] T. G. Bonney, 'Coll. Rock-specims. fr. I. of Socotra,' Phil. Trans. Roy. Soc. vol. clxxiv (1883) pp. 273–94 & pls. vi–vii.

[3] C. A. Raisin, 'Rock-specims. fr. Somaliland' Geol. Mag. 1888, pp. 414–18.

Localities.	*N. Lat.*		*E. Long.*		*District.*	*Altitudes in feet.*	
Dobar	10°	20′	45°	5′	Guban	appr. 800	Coarse syenitic gneiss.
Busti	10	16	45	4	„	„ 900	Gneiss.
Bihendula	10	10	45	5	„	„ 1000	Amphibolite-schist.
Wagga Mt.	10	2	45	25	Golis	„ 4000	Gneiss, mica-schist, chloritic schist, and amphibolite.
Duban	10	10	45	25	Guban	...	Gneiss and pegmatite.
'Hau Kideali'					Wagga	...	Gneiss (coll. by Miss F. Gillett).
Daimoli	10	7	45	3	Guban	3094	Gneiss and amphibolite.
Between Bihin and Daimoli	10	9	45	4	„	...	Gneiss.

III. The Somaliland Limestones.

In 1896 it was uncertain whether the limestones were restricted to the Guban or whether any member of the series occurred on the northern part of the plateau. This point was important, as upon it depended the question whether the Haud had been below sea-level in Kainozoic times, or whether it was part of a very ancient land-area, round the flanks of which the limestones had been deposited.

The collections now prove conclusively that marine limestones of Cretaceous and early Kainozoic date do occur on the summit of the Haud. This view appeared probable, on account of the abundance of irregular chert-fragments scattered over the surface of the plateau; but this evidence was not conclusive, as the cherts might have been carried up by the makers of the Palæolithic stone-implements found upon the plateau. The existence of the high-level limestones is demonstrated indirectly by the occurrence of thick deposits of calcareous tufa at various points on the edge of the Haud, as at Wagga, where some beds of tufa with leaf-remains are exposed, at Gedais and at the Upper Sheikh Pass, where there are encrustations of compact stalagmitic limestone. These deposits show that there must have been some considerable amount of calcareous rock at higher levels than that at which the tufa now occurs. Fortunately there is also direct evidence, as Mr. Aylmer has collected specimens of limestone *in situ* at the following localities:—

Localities.	*Altitudes in feet.*	*Position.*
Sok Soddah............	4300	South of the Rugga Pass.
Wagga	4000	A spur of the Golis, north-east of the Rugga Pass.
By highest point of Abdullah Ismail...	about 5300	South of the Golis, west of Sheikh.
Between Burao and Bur Dab	„ 3000	The Haud, approximately 9° 20′ lat. N. & 45° 50′ long. E.
Derkamli Libah, south of Burao ...	„ 3000	The Haud.

At Burao and Derkamli Libah the rocks are banded cherts and foraminiferal limestones. Limestones have also been recorded by

Mr. Parkinson[1] from the sides of the Miriya Pass, above Dongorreh, in the ranges of Artalla and Bur Dab, and as far south as God-la-Yareh.

Hence it is clear that the marine limestones are widely distributed in Somaliland on the summit of the plateau. As some limestones of the same age also occur in the low-lying Guban at the foot of the plateau-scarp, the formation of the Aden depression was later than the deposition of the high-level limestones, for the age of which we must turn to the palæontological evidence.

IV. The Fossil Corals of Somaliland.

Description of the Species.

Genus Stylophora, Schweigger, 1820.

1. Stylophora pistillata (Esper).

1797. *Madrepora pistillata*, Esper, 'Pflanzenth.' Fortsetz. vol. i, p. 73, Madrep. pl. lx.

1820. *Stylophora pistillaris*, Schweigger, 'Handb. Naturg.' p. 414; 1879. *St. pistillata*, Klunzinger, 'Korallth. roth. Meer.' pt. ii, p. 62.

Distribution.—Raised Reefs, Guban near Berbera. Coll. Capt. E. T. Marshall.

2. Stylophora palmata (de Blainville).

1830. *Sideropora palmata*, de Blainville, Zooph. in Dict. Sci. Nat. vol. lx, p. 350.

1857. *Stylophora palmata*, Milne-Edwards & Haime; 'Hist. Nat. Cor.' vol. ii, p. 137; 1879. Klunzinger, 'Korallth. roth. Meer.' pt. ii, p. 63.

Distribution.—Raised Reefs: Guban, near Berbera. Coll. Capt. E. T. Marshall. This 'species,' which may be only a form of *St. pistillata* with more compressed branches, is represented by a small specimen.

3. Stylophora frondosa, sp. nov. (Pl. I, figs. 1 *a*–1 *c*.)

Diagnosis.—Corallum large and cæspitose; with thick, strongly compressed, twisted branches. Corallites small, about 1 mm. in diameter, very crowded; the calices are deep and the lower margins raised. Columella prominent.

Septa in one cycle; all six septa equal in size and united to the columella. Endotheca in distant, tabuliform lamellæ.

Distribution.—Duban: low-level alkali plain, north of the foot of the Rugga Pass. Coll. Mrs. Lort Phillips.

Affinities.—This coral occurs as a series of branches ramifying through a large block of limestone. In many places the coral has been removed, leaving the interspaces as confluent sheets of limestone ornamented by minute granulations or tubercles which are the casts of the calices. These bands of limestone stand out as branched expanded sheets, resembling in appearance a crateriform sponge. The branches of the coral occur as depressions between the raised limestone-bands; and it was only by breaking away the latter that

[1] F. B. Parkinson, 'Two recent Journeys in Northern Somaliland' Geogr. Journ. vol. xi (1898) pp. 17, 19, 25 & 28.

the real fossil was displayed, and proved to be a *Stylophora* instead of a Latusastræan coral as had been at first suspected.

The main characters of the species are the narrowness of the cœnenchyma and the crowded arrangement of the corallites.

Genus Stylina, Lamarck, 1816.

1. Stylina subtabulata, sp. nov. (Pl. I, figs. 2 *a* & 2 *b*.)

Diagnosis.—Form of corallum unknown. The corallites are of medium size and crowded. They are circular or elliptical in transverse section.

The septal symmetry is pentagonal or hexagonal, rarely heptagonal. The septa belong to two complete cycles, with one or two small septa representing the third cycle in a few of the primary loculi. The primary septa are thick and conspicuous, whereas the secondary septa are short and thin. Costæ short, thick, and prominent.

The columella is very small.

The dissepiments are stout, and in longitudinal sections may resemble tabulæ.

Dimensions.—Diameter of corallites =3 to 5 mm.; distance of calicinal centres =4 to 7 mm.

Distribution.—Dobar Limestone: Dobar, south of Berbera. Coll. Mrs. Lort Phillips.

Affinities.—In general aspect, this coral closely resembles *Cryptocœnia Picteti*, Koby, from the Swiss Urgonian; but in the Somaliland coral there is a distinct columella in many corallites, and the diameter of the corallites is, on the average, nearly twice as great. In septal characters the species agrees with the Upper Senonian *Stylina geminata* (Goldf.), from Maastricht; but the corallites are larger and the columella is smaller.

An interesting feature in this species is the strong development and subtabulate arrangement of the dissepiments; the presence of definite tabulæ in the closely-allied genus *Cyathophora* may be thus explained as merely exaggerated dissepiments.[1]

2. Stylina Lort-Phillipsi, Gregory.

1896. *Cryptocœnia Lort-Phillipsi*, Gregory, Geol. Mag. p. 291.

Distribution.—Dobar Limestone, Dobar. Coll. Mrs. Lort-Phillips.

Genus Calamophyllia, de Blainville, 1830.

Calamophyllia Aylmeri, sp. nov. (Pl. I, fig. 3.)

Diagnosis.—Corallum with the corallites widely separated, the interspaces being usually wider than the diameter of the corallites. The corallites are circular or elliptical in transverse section, and are slightly sinuous. They are connected by occasional collerettes, which are somewhat thick and lamellar.

[1] Koby, Mém. Soc. Pal. suisse, vol. xxiii, 'Mon. Polyp. Crét. Suisse' pt. ii (1897) p. 32 & pl. ii, fig. 11.

The septa are very thin, and belong to three cycles. There is no columella, and the endotheca is very scanty.

Dimensions.—Diameter of corallites = 1·5 to 2 mm.; average distance of calicinal centres = 5 mm.

Distribution.—Uradu Limestone, near Uradu; north of the foot of the Rugga Pass. Coll. Mrs. Lort Phillips.

Affinities.—This species resembles *C. radiata* (Lamx.),[1] from the Bathonian, in the small size of its corallites; but it differs from that coral by the more open growth of the corallum, the greater number of septa, and less sinuous corallites. The general characters of the corallum are more like those of *Stylosmilia* than of *Calamophyllia*; but owing to the absence of the columella it is included in the latter genus. In the description of the Kach corals I have expressed doubt as to the continued separation of these two genera;[2] the presence of the-well developed columella is the distinctive feature of *Stylosmilia*.

Genus Galaxea, Oken, 1815.

Galaxea irregularis (Milne-Edwards & Haime).

1848. *Sarcinula irregularis*, Milne-Edwards & Haime, 'Monogr. des Astréides' Ann. Sci. Nat. ser. 3, vol. x, p. 316.

1851. *Galaxea irregularis*, Milne-Edwards & Haime, 'Polyp. Foss. des Terr. Paléoz.' Arch. Mus. Hist. Nat. vol. v, p. 71; 1857. 'Hist. Nat. Cor.' vol. ii, p. 229 & pl. D 2, fig. 2; 1879. Klunzinger, 'Korallth. roth. Meer.' pt. ii, p. 78 & pl. vii, fig. 11.

Distribution.—Raised reefs. In the Guban, near Berbera. Coll. Capt. E. T. Marshall.

Genus Orbicella, Dana, 1848.

Orbicella mammillosa, Klunzinger.

1879. *Orbicella mammillosa*, Klunzinger, 'Korallth. roth. Meer.' pt. iii, p. 49 & pl. v, fig. 5, pl. x, figs. 10 *a*–10 *c*.

Distribution.—Raised Reefs. In the Guban, near Berbera. Coll. Capt. E. T. Marshall.

Genus Columnastræa,[3] d'Orbigny, 1849.

The inclusion of the following fossils in this genus necessitates a slight alteration in its accepted definition, which we owe to Milne-Edwards & Haime; for in one species, if not in more, there are two crowns of pali instead of only one, as in the type-species. The genus is nearly allied to *Cyathomorpha*, which has more numerous septa.

1. Columnastræa bicoronata,[4] sp. nov. (Pl. II, figs. 7–9.)

Diagnosis.—Corallum massive, apparently in nodular or hemispherical masses.

The corallites are of medium size; the average diameter is

[1] *Eunomia radiata*, Lamouroux, Exp. Méth. p. 83 & pl. lxxxi, figs. 10–11.
[2] Gregory, 'Jur. Fauna Cutch' Pal. Ind. ser. 9, vol. ii, pt. ii, pp. 49–50.
[3] This name was originally spelt *Columastræa* by d'Orbigny.
[4] Having two crowns of pali.

about 4 mm. The corallites are separated by distinct but narrow spaces, with comparatively little exotheca. The walls are thick.

Septa in three complete cycles; they are thick at the base and taper rapidly.

The columella is small and inconspicuous.

Pali: one crown of six strong cylindrical pali, alternating with which are six thin, inconspicuous lamellar pali.

Dimensions (of three specimens).—

	No. 31.	No. 32.[1]	No. 16.
	mm.	mm.	mm.
Diameter of the corallites	3 to 5	4 to 5	4 to 6
Distance of calicinal centres......	4·5 to 5·5	5 to 5·5	5 to 7
Corallum: diameter	broken fragment	...	75 by 65
„ height...................	70 by 50	85	40

Distribution.—Uradu Limestone: near Uradu, south of Dobar, and in the Duban. Coll. Mrs. Lort Phillips.

Affinities.—*Columnastræa bicoronata* differs from previously-described species of the genus by its double crown of pali and the greater size of the corallites. The spaces between the corallites are sometimes completely filled by calcareous material, in such wise that the corallites appear united by solid walls.

2. Columnastræa Phillipsiæ, sp. nov. (Pl. II, fig. 10.)

Diagnosis.—Corallum massive.

Corallites very small: the average diameter being about 2 mm. The corallites are closely crowded, but internally appear definitely separated by narrow intermediate spaces. Exotheca very scanty. The corallites in section are usually circular or elliptical, but are sometimes subtrigonal. Distance of the calicinal centres = 2·5 mm.

Septa very thin; the primary are decidedly more distinct than the secondary. There are three complete cycles and some representatives of a fourth cycle.

Columella small, and often appearing trabecular, owing to its union with the pali.

Pali in one complete crown, and in some corallites irregular representatives of a second crown occur.

Distribution.—Uradu Limestone: Uradu, near the foot of the Rugga Pass. Coll. Mrs. Lort Phillips.

Affinities.—This coral may be easily distinguished from the other Somaliland *Columnastrææ* by the small size of its corallites. In this character it approaches *C. striata* (Goldf.),[2] the type of the genus; and that Turonian species also has traces of a fourth cycle. *C. Phillipsiæ* differs, however, from *C. striata* by having the corallites more crowded, less uniform in shape, the pali less regular, and the septa of the different cycles less equal in size.

[1] This specimen, from south of Dobar, has a much altered corallum, the pali are obscurely indicated in a few calices only, and the determination is doubtful.

[2] *Astræa striata*, Goldfuss, 'Petref. Germ.' pt. i (1829) p. 111 & pl. xxxviii, fig. 11.

C. similis, M.-Ed. & H.[1] has corallites of a similar size, but has the septa less numerous and well developed than those of *C. Phillipsiæ*.

3. Columnastræa maxima, sp. nov.

Diagnosis.—Corallum nodular; comparatively small.

Corallites very large; fused together by thick walls, which, in weathered specimens, stand out above the level of the corallum, separating the depressed calices.

Septa in three orders.

Dimensions.—Diameter of corallites = 10 to 12 mm.; distance of calicinal centres = 12 to 13 mm.

Distribution.—Uradu Limestone: Uradu. Coll. Mrs. Lort Phillips.

Genus Prionastræa, Milne-Edwards & Haime, 1848.

Prionastræa crassisepta, sp. nov. (Pl. I, figs. 5 *a*, 5 *b*, & 6.)

Diagnosis.—Corallum in rounded masses; heavily calcified. The corallites are large, polygonal, closely crowded, and intimately united throughout by their walls.

Calices comparatively shallow.

Septa in four complete cycles; the primary and secondary septa are very thick, and reach the columella.

Columella broad, but not very conspicuous; it is about one-fifth of the diameter of the corallite, and composed of very spongy tissue.

Dissepiments abundant.

Dimensions.—Diameter of corallum = 90 by 70 mm.; of average corallite = 20 mm.; of columella of the same = 4 mm.

Distribution.—Dobar Limestone: Dobar, south of Berbera. Coll. Mrs. Lort Phillips.

Affinities.—This coral resembles *Dimorphocœnia crassisepta*, de From.[2] by the great thickness of its septa; but it differs by the presence of the columella, the absence of the concentric arrangement of the corallites, and other characters. The septa are thicker than in any other known species of *Prionastræa*, of which it is the earliest representative. The previous records of the genus from the Jurassic are based on species of *Isastræa*.

Genus Cœloria, Milne-Edwards & Haime, 1848.

1. Cœloria arabica, Klunzinger.

1879. *Cœloria arabica*, Klunzinger, 'Korallth. roth. Meer.' pt. iii, p. 17 & pl. ii, figs. 1, 3, 8; pl. ix, fig. 10.

Distribution.—Raised reefs. In the Guban, near Berbera. Coll. Capt. E. T. Marshall. Two small fragments.

[1] Milne-Edwards & Haime, 'Monogr. des Astréides' Ann. Sci. Nat. ser. 3, vol. xii (1849) p. 184.

[2] E. de Fromentel, 'Descr. Polyp. foss. Étage Néocom.' (1857) p. 55 & pl. viii, fig. 1.

Genus Favia, Oken, 1815.

1. Favia lobata (Milne-Edwards & Haime).

1849. *Parastræa lobata*, M.-E. & H. 'Monogr. des Astréides' Ann Sci. Nat. ser. 3, vol. xii, p. 171.
1857. *Favia lobata*, M.-E. & H. 'Hist. Nat. Cor.' vol. ii, p. 434 & pl. D 8, fig. 3.

Distribution.—This coral is abundant in the existing reefs of the Red Sea, and occurs in the raised reefs of Egypt and Sinai. The specimen collected by Mrs. Lort Phillips is much altered; though it has larger calices than is usually the case in *F. lobata*, there is no doubt that it belongs to that species. It was found at Dobar, but was probably carried there as building-material from the raised limestones of the Somali coast, near Berbera. It is the only Pleistocene species that is represented in Mrs. Lort Phillips's collection.

2. Favia somaliensis, sp. nov. (Pl. I, figs. 4 *a* & 4 *b*.)

Diagnosis.—Corallum nodular; small.

Corallites of medium size, elliptical, quadrangular, or subtrigonal; in very short series. The walls are usually from 3 to 4 mm. thick, although the walls between newly-separated corallites may be only 1 mm. thick.

The septa belong to three complete cycles, with some representatives of a fourth. The septa of the primary and secondary cycles are subequal.

Dimensions.—Diameter of corallites = 5 to 8 mm.; distance of calicinal centres = 6 to 8 mm.; corallum: diameter = 55 by 70 mm.; height = 35 mm.

Distribution.—Uradu Limestone: Uradu. Coll. Mrs. Lort Phillips.

Affinities.—This coral may be regarded as a larger, coarser form of *F. Lorioli*, Koby,[1] from the Swiss Urgonian. Our coral may be only a geographical variety of that species, having corallites twice the width, owing to growth under more tropical conditions. As the only known corallum, however, is no larger than those of the Swiss species, this hypothesis must be regarded as merely a tentative suggestion.

Genus Metethmos, Gregory, 1899.[2]

Diagnosis.—Ethmotidæ in which the corallum is simple and the calice shallow; some of the septa are perforated near their inner and upper ends, but the pores in the older septa and near the wall are closed by stereoplasm. Synapticulæ scarce. Columella well developed, papillary.

Affinities.—This genus was founded for some Bathonian corals from Kach, of which the type is *M. Blanfordi*, Greg.

[1] Koby, Mem. Soc. Pal. suisse, vol. xxiii 'Monogr. Polyp. Crét. Suisse' pt. ii (1897) p. 53 & pl. x, figs. 6–7.
[2] 'Jur. Fauna Cutch' Pal. Ind. ser. 9, vol. ii, pt. ii, p. 165.

METETHMOS ASYMMETRICA, sp. nov. (Pl. II, figs. 11 *a* & 11 *b*.)

Diagnosis.—Corallum large and cornutiform. The base is pointed, and the upper surface flat; the transverse section is elliptical. Columella about one-tenth the diameter of the corallum. Excentric in position, being nearer the convex side.

Septa large and crowded, and unsymmetrically developed on the two sides of the columella. The septa are longer and more numerous on the concave side of the corallum, where they occur in six incomplete cycles. On the opposite side there are only four cycles.

The primary and secondary septa are thick, and appear imperforate; in the section on the concave side of the corallum the tertiary septa may be the same, but on the other side the tertiary septa and those of higher orders are thin and perforate.

Dimensions.—Height of corallum = 60 mm.; diameter, major = 40 mm., and minor = 29 mm.; diameter of columella = 4 by 3 mm.

Distribution.—Dobar Limestone: Dobar. Coll. Mrs. Lort Phillips.

Affinities.—Externally this coral strikingly resembles *Montlivaltia cornutiformis*, Greg.[1] but may be distinguished from it in transverse sections. It is much larger than the two Indian Jurassic species of *Metethmos*, and the septa are more numerous.

Asymmetry in the septal sequence on either side of the axis of the corallum is not unusual in corals with a curved axis, and is well illustrated in this species. The septal sequence in two opposite sectors is as follows:—

1	10	6	4	8	11	3	9	5	7	2	7	5	9	3	8	4	6	1
1			4			3		5		2		5		3		4		1

Genus CYCLOLITES, Lamarck, 1801.

1. CYCLOLITES HELIOPHANA, de Rochebrune.

1882. *Cyclolites heliophana*, A. T. de Rochebrune, 'Obs. géol. & pal. Région Çomalis' Mission Révoil, Faune & Flore des Pays Çomalis, pt. vii, p. 38 & pl. iv, fig. 1.

Diagnosis.—Corallum orbiculate, subconvex above, concave below. Calicular fossa round. Septa equal, very thin and straight; laterally covered with alternately-arranged conical granules.

Dimensions.—Diameter = 43 mm.; height = 19 mm.

Distribution.—Neocomian (?); Amura, Singeli District.

2. CYCLOLITES PHILLIPSIÆ, sp. nov.

Diagnosis.—Corallum large, elliptical, and thick. The base is uneven. The columellar fossa is short.

Septa very numerous, amounting to about seven cycles. The primary septa measure as much as 3 mm. in thickness. The septa occur as isolated trabeculæ in only the highest orders; in the lower orders the trabeculæ are united by stereoplasm.

[1] 'Jur. Fauna Cutch' Pal. Ind. ser. 9, vol. ii, pt. ii (1899) p. 85 & pl. iv, fig. 7.

Distribution.—Uradu Limestone: near the Rugga Pass. Coll. Mrs. Lort Phillips.

Affinities.—This species is founded on a single coral from the Uradu Limestone, which is unfortunately so much weathered that its form is somewhat uncertain. The specimen measures 100 mm. in length, 80 mm. in breadth, and 33 mm. in height. There is no epitheca left on the base, but its absence may be due to erosion.

The coral is a close ally of the Turonian *C. crassisepta*, de From.[1] from which it differs by its shorter columellar fossa, also by having the thick septa equally developed in all directions, and not especially on the sides of the corallite. The new species agrees far more with the Turonian than with the Neocomian, Rhodanian, and Aptian species.

The four Indian Turonian species of *Cyclolites* are much smaller, and belong to a more primitive type of the genus.[2]

Genus Litharæa, Milne-Edwards & Haime, 1849.

1. Litharæa Colæ, sp. nov. (Pl. II, figs. 12 *a* & 12 *b*.)

Diagnosis.—Corallum small, lamellar; probably growing in thin flat encrustations. Corallites small and crowded, and separated by thick walls.

Calices very deep. Columella small, and barely recognizable on the surface.

Septa in two cycles; irregular in thickness, and rather sinuous.

Dimensions.—Diameter of calices = 1·5 mm., and distance of calicinal centres = 2 mm.; corallum: thickness = 10 mm., and diameter = 28 mm.

Distribution.—Uradu Limestone: Uradu. Coll. Mrs. Lort Phillips.

Affinities.—This species is characterized by its small corallites, deep large calices, and thick walls or bands of cœnenchyma. The genus has hitherto been recorded no earlier than the Upper Cretaceous. The species of *Litharœa* which this coral most resembles is probably *L. Deshayesiana* (Mich.)[3] which agrees with it in the dimensions of the corallites and number of septa, but has thinner cœnenchymal bands. The new species differs from *L. epithecata*, Dunc.[4] from the Upper Cretaceous of Sind, by the smaller size of the corallites, the fewer septa, and the narrower wall.

2. Litharæa Parkinsoni, sp. nov. (Pl. II, figs. 13 & 14.)

Diagnosis.—Corallum growing in cylindrical branches measuring from 10 to 20 mm. in diameter. The corallites are of medium

[1] E. de Fromentel, 'Pal. franç. Terr. Crét.: Zooph.' vol. viii (1864) pl. lvi & *ibid.* (1867) p. 334.

[2] Stoliczka, 'Cret. Fauna S. Ind.' Pal. Ind. vol. iv, pt. iv (1873) pp. 48 & 49.

[3] Michelin, 'Iconogr. Zooph.' (1840–47) p. 164 & pl. xlv, fig. 4.

[4] P. M. Duncan, 'Sind Foss. Cor. & Alcyon.' Pal. Ind. ser. 14, vol. i, pt. ii 1880) p. 23 & pl. ii, figs. 1–9.

size, with broad, shallow calices, sometimes separated by raised walls 1 mm. thick.

The columella is distinct, and stands up as a blunt prominence, surrounded by six paliform lobes formed by the union of the primary and secondary septa.

Septa in three cycles; those of the first two cycles meet near the columella.

Dimensions (of two specimens).—

	mm.	mm.
Diameter of calices	3 to 4	3 to 4
Distance of calicinal centres	4 to 5	4 to 5
Diameter of branch of corallum ...	20	16

Distribution.—Cherty Limestone: Somali Plateau. Coll. Mr. F. B. Parkinson.

Affinities.—This interesting coral appears on first examination similar to a *Thamnastræa*, though the application of a hand-lens at once shows that it is a perforate species. The presence of six pali in some corallites raised doubts in my mind as to the generic position of the coral; from a study of the specimens collected by Mr. Parkinson it seems probable, however, that there are no true pali, but only paliform lobes. The species may thus enter *Litharæa*, where its nearest ally is *L. epithecata*, Dunc. from the Upper Cretaceous of Sind; Duncan's species has, however, a small hemispherical and not a branched corallum.

The specimen was collected from the cherty limestones which overlie the cave-forming *Nerinæa*-limestone above the Miriya Pass, and around God-la-Yareh, south of Bur Dab (8° 30′ lat. N. & 46° 30′ long. E.).

Genus Dendracis, Milne-Edwards & Haime, 1849.

Dendracis sp.

Mr. Parkinson's collection includes a worn branch of a dendroid coral, which measures 9 mm. in diameter; the calices are slightly over 1 mm. in diameter, and the calicular margins are well raised. The species is closely allied to *D. nodosa*, Rss.[1] but the specimen is too small for definite determination.

The specimen came from the cherty limestone, which overlies the *Nerinæa*-limestone.

Genus Turbinacis, nov.

Diagnosis.—Corallum arborescent. Cœnenchyma in narrow bands, variable in width. Calices small, circular, usually crowded. Septa in adult calices numerous and subequal; six large primary septa in young calices. Columella large and parietal. No pali. Tabulæ present.

[1] A. E. von Reuss, 'Pal. Stud. über die älteren Tertiärschichten der Alpen: pt. i. Anthozoen der Schichten von Castelgomberto' Denkschr. d. k. Akad. Wissensch. Wien, vol. xxviii (1868) pp. 172, 178 & pl. xv, figs. 2, 5.

Type-species.—*Turbinacis erythrœensis*, sp. nov. Pleistocene: Somaliland.

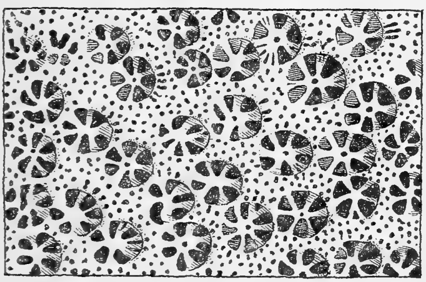
Affinities.—This genus has the habit of a *Stylophora*, the numerous subequal septa of a *Turbinaria*, and the calices of an *Actinacis*. It is most closely allied to the last-named genus, from which it differs by the absence of pali, the more scanty cœnenchyma, and the more numerous septa. It differs from *Astrœopora*, which it resembles in the character of the cœnenchyma, by the presence of a prominent, well-developed columella. From *Turbinaria* it differs by its arborescent habit, the more scanty cœnenchyma and the prominence of the primary septa in younger calices.

Turbinacis erythræensis,[1] sp. nov. (Text-figs. 3 *a* & 3 *b*.)

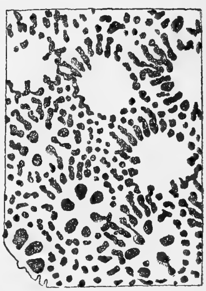
Diagnosis.—Corallum of slender, cylindrical, dichotomous branches. Cœnenchyma very variable in width, ranging from a thin band, nearly equal in width to the calices, till it is practically absent. Externally the cœnenchyma appears porous, as it is pierced by numerous circular punctations.

Septa in young calices six in number, and prominent; in older corallites the number of septa increases, and they fuse into groups

Fig. 3.—Turbinacis erythræensis, *gen. et sp. nov.*



a. × 6 diam.



b. × 7 diam.

a = Part of the surface of the corallum.
b = Part of a transverse section of the same.

of six, which resemble six thick primary septa. In the mature corallites the number is about thirty, and they are all subequal.

Columella large, often hollow; sometimes it appears styliform.

Dimensions.—Diameter of branch = 10 mm.; of calices = 1 mm.; width of cœnenchyma = ·2 to ·8 mm.

Distribution.—Pleistocene; raised reefs, near Berbera, Somaliland. Coll. Capt. E. T. Marshall.

[1] From *Mare Erythrœum*, the Red Sea.

LIST OF SOMALILAND FOSSIL CORALS.

Species.		Pleistocene.	Duban.	Uradu Limestone.	Dobar Limestone.	Remarks.
Stylophora pistillata	(Esper)	*				
„ *palmata*	(Blv.)	*				
„ *frondosa*	nov.		*			
Stylina subtabulata	„				*	
„ *Lort-Phillipsi*	„				*	
Calamophyllia Aylmeri	„			*		
Galaxea irregularis	(M.-Ed. & H.)	*				
Orbicella mammillosa	Klz.	*				
Columnastræa bicoronata	nov.		*	*		And near Dobar.
„ *Phillipsiæ*	„			*		
„ *maxima*	„			*		
Prionastræa crassisepta	„				*	
Favia lobata	(M.-Ed. & H.)	*				
„ *somaliensis*	nov.			*		
Cœloria arabica	Klunz.	*				
Metethmos asymmetrica	nov.				*	
Cyclolites heliophana	Rochebr.					Neocomian (?) of Amura.
„ *Phillipsiæ*	nov.			*		
Litharæa Colæ	„			*		
„ *Parkinsoni*	„					'Cherty Limestone,' (32) Turonian.
Heliopora	„			*		
Dendracis sp.						'Cherty Limestone,' (32) Turonian.
Turbinacis erythræensis	nov.	*				

V. The Fossil Echinoidea of Somaliland.

The collection includes specimens of two species of Echinids.

Pseudodiadema somaliense, sp. nov. (Text-figs. 4 & 5.)

Diagnosis.—Test small, depressed, circular. Base flat, rounded above; ambitus tumid.

Ambulacra: the pairs of pores are biserial close to the peristome; elsewhere the pairs are straight and uniserial. There are no primary tubercles on the ambulacra; but in each area are four vertical rows of granules, with some scattered granules of an extra median series. The granules near the pores are larger than the internal series.

Fig. 4.—*Abactinal surface of* Pseudodiadema somaliense, *sp. nov.* (×4 *diam.*)

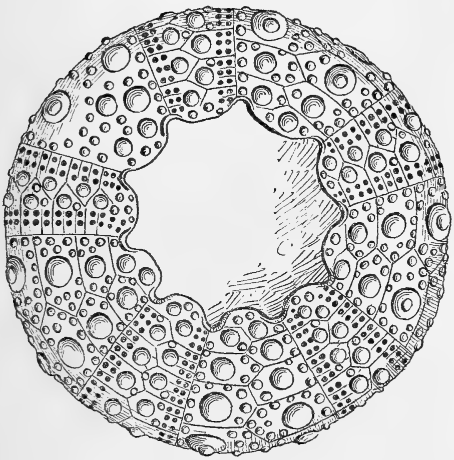
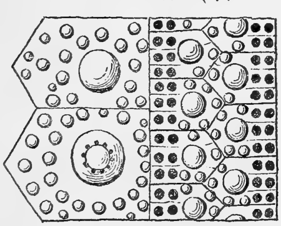


Fig. 5.—*Part of a specimen of* Pseudodiadema somaliense. (×6 *diam.*)



[To show the uppermost ambital interambulacral plate, the plate above it, and the adjacent ambulacral plates.]

Interambulacra: about seven plates in each vertical series; the plates are of the cidaroid type, and have one primary tubercle each; the tubercles of the three uppermost plates are small, the size suddenly increases, and the tubercles of the ambital plates are large. The scrobicular circles are complete in the upper plates, but at the ambitus the scrobicular areas are confluent. Outside the scrobicular circles the plates are covered by numerous, crowded granules. Peristome large; roughly decagonal. Branchial incisions large.

Dimensions.—Diameter of test = 13 mm.; height of test = 6·5 mm.; width of interambulacrum at ambitus = 2 mm.; of ambulacrum at ambitus = 5·5 mm.; diameter of peristome = 6·55 mm.

Distribution.—Bihendula Limestone: Bihendula, south of Berbera.

Affinities.—The main characters of this species are the absence of tubercles in the ambulacra, and the occurrence there of four to five rows of granules. It belongs to the same group of species as the Bajocian *Ps. Jauberti*, Cott.[1] in which, however, the pore-pairs are not doubled near the peristome. *Ps. muelense*, P. de Lor.[2] from the Sinemurian of Portugal, agrees in the extensive ornamentation of the interambulacral plates; but though its ambulacral tubercles are small, they are much larger than in *Ps. somaliense.*

? Conoclypeus, sp.

In Mr. F. B. Parkinson's collection there is a large flat echinid of which the base is all but lost. Its generic determination is therefore impossible, but it may be useful to record the specimen for reference, in case other imperfect specimens should be found. The specimen came from a massive limestone, which is no doubt Eocene, as Mr. C. D. Sherborn and Mr. F. Chapman have kindly identified some foraminifera in the matrix as *Nummulites* sp., *Amphistegina* sp., and *Orbitoides dispansa* (Sow.).

The specimen came from the beds of limestone associated with gypsum on the Somali plateau. The exact locality is apparently Kirrit (lat. 9° N. and long. 46° 10′ E.), south of Bur Dab.

VI. The Limestone Sequence and the Date of the Foundering of the Aden Gulf.

The palæontological evidence at present available shows that the limestones of Somaliland belong to five different ages—Lower Jurassic, Neocomian, Turonian (? Cenomanian), Eocene, and Pleistocene.

The oldest of the five limestones occurs at Bihendula, near the foot of the plateau-scarp, some 20 miles south of Berbera. Mrs. Lort Phillips collected four species of fossils from this locality in 1894–95. They were two species of brachiopoda, determined by Mr. F. A. Bather as *Rhynchonella Edwardsi*, Chapuis & Dewalque, and *Rh. subtetrahedra*, Dav.; a lamellibranch identified by Mr. R. B. Newton[3] as *Parallelodon Egertonianus*, Stoliczka; and a belemnite, recorded by Mr. G. C. Crick[4] as *B. subhastatus*, Zieten. The Bihendula Limestone was accordingly determined as of Lower Jurassic, and probably of Bathonian age. The belemnite is characteristic in India of the *macrocephalus*-zone, the lowest part of the Callovian; Mr. Crick distinguished it from *B. tanganensis*, Futterer, of the Lower Oxfordian of East Africa, and suggested that it might be identical with the fossil from Shoa, identified by H. Douvillé[5] as

[1] G. Cotteau, 'Echinides Réguliers,' Pal. franç. Terr. Jur. vol. x, pt. ii (1881) p. 238 & pl. cccxxiii, figs. 6–14.

[2] P. de Loriol, 'Descr. Faune Jur. Portugal, Embr. des Echinod.' pt. i (1890) p. 82 & pl. xv, figs. 1–5.

[3] R. B. Newton, 'Occurr. of an Indian Jur. Shell in Somaliland' Geol. Mag. 1896, pp. 294–96.

[4] G. C. Crick, 'Fragm. of Belemn. fr. Somaliland' *ibid.* pp. 296–98.

[5] H. Douvillé, 'Foss. rapp. du Choa par M. Aubry' Bull. Soc. géol. France, ser. 3, vol. xiv (1886) p. 223.

Belemnopsis sulcata. The *Parallelodon*, according to Mr. Newton, suggested a slightly older date, for he described it as identical with a specimen from the Niti Beds, where it is associated with *Parkinsonia Parkinsoni.* The Bihendula Limestones were accordingly suggested to be of Bathonian age; but with the larger collection now available it seems probable, from the cephalopoda, that some Callovian beds are represented at Bihendula, and possibly the whole fauna may be Callovian.

The Dobar[1] Limestone has yielded four species of corals and two Neocomian mollusca, which Mr. R. B. Newton has kindly identified as *Alectryonia rectangularis* (Röm.) and *Modiola Ferreti* (Rochebr.).[2] The evidence of the corals agrees with that of the mollusca, and the Dobar Limestone accordingly may be determined as Neocomian and approximately correlated with the Singeli limestone described by A. T. de Rochebrune, the Faf limestones discovered by Keller, and the cave-forming or *Nerinæa*-limestone of the Miriya Pass and Bur Dab. Mr. Parkinson has collected from Bur Dab a large *Nerinæa* and a *Natica* which Mr. R. B. Newton tells me are of Neocomian affinities, and from the cave-forming limestone at Dongorreh a specimen of a *Nerinæa*, also of the Neocomian type.[3]

Above the Neocomian beds occurs a thick series of limestones which include Turonian (or possibly Cenomanian) and Eocene representatives. The lowest part of this series is formed by a cherty limestone from which, in the neighbourhood of Bur Dab, Mr. Parkinson collected some broken mollusca; these specimens have been determined by Mr. Newton as *Gryphæa vesiculosa*, J. de C. Sow., *Pecten* sp. nov., and *Spondylus* sp., and he therefore suggests that the horizon is Cenomanian. A richer fauna has been obtained by Mrs. Lort Phillips in Uradu, near the Rugga Pass; she collected there eight species of corals, which are certainly Upper Cretaceous and correspond most nearly to Turonian species.

The upper part of this limestone series is no doubt Lower Kainozoic and probably Eocene. It has yielded an indeterminable species of *Conoclypeus* and some foraminifera, among which Mr. C. D. Sherborn and Mr. F. Chapman have identified species of *Nummulites* and *Amphistegina*, and *Orbitoides dispansa* (Sow.). The limestone of Mount Eilo, south of Zeila, may represent this horizon in Western Somaliland.

The last of the five limestones consists of the raised reefs south of Berbera, which are Pleistocene.

[1] Also spelt Duba and Dubbur.

[2] This species was founded on a specimen from Antalo, and its occurrence at Dobar supports M. de Rochebrune's contention as to the Cretaceous age of the Antalo limestone.

[3] The mollusca have been determined by Mr. Newton as *Nerinæa*, allied to *Renauxiana*, d'Orb., a *Nerinæa* sp. nov., and *Natica*, allied to *Hugardiana*, d'Orb., and as probably denoting a Barremian (that is, Urgonian or Upper Neocomian) age.

Our knowledge of the faunas of these five limestones is unfortunately scanty, and further collections would be welcomed from the limestones of Bur Dab, Artalla, Wagga, Abdullah Ismail, and especially from the highest beds above the Miriya Pass, also from the limestones associated with the gypsum-beds of Kirrit, Eyk, and the Duban. But the evidence of the present collections is sufficient to show that a Neocomian limestone occurs both on the summit of the Somali plateau and on the floor of the Guban, and that some marine limestones of probably Lower Tertiary (Eocene) age also occur on the plateau.

It seems therefore probable that the foundering of the Aden Gulf is post-Eocene in age.[1]

EXPLANATION OF PLATES I & II.

Plate I.

Fig. 1. *Stylophora frondosa*, sp. nov. Duban, north of the foot of the Rugga Pass. Coll. Mrs. Lort Phillips. a = part of the surface of the corallum, × 3 diam.; b = a horizontal section through part of the same, × 6 diam.; c = a vertical section through part of the same, × 6 diam. (See p. 30.)

2. *Stylina subtabulata*, sp. nov. Dobar Limestone: Dobar, south of Berbera. Coll. Mrs. Lort-Phillips. a = part of a horizontal section, × 2 diam.; b = part of a vertical section through the same specimen, × 2 diam. (See p. 31.)

3. *Calamophyllia Aylmeri*, sp. nov. Uradu Limestone, near Uradu. Coll. Mrs. Lort Phillips. Part of a horizontal section, × 3 diam. (See p. 31.)

4. *Favia somaliensis*, sp. nov. Uradu Limestone, Ura du. Coll. Mrs. Lort Phillips. a = part of the corallum, showing some calices as seen from the surface, and others in section, nat. size; b = transverse section across one corallite, × 4 diam. (See p. 35.)

Figs. 5 & 6. *Prionastræa crassisepta*, sp. nov. Dobar Limestone, Dobar, south of Berbera. Coll. Mrs. Lort Phillips. Fig. 5 b = transverse section of part of a corallum, nat. size; fig. 5 a = upper surface of a corallite from the same specimen, showing columella, × 2 diam.; fig. 6 = part of a vertical section through another specimen, showing columella, walls, and dissepiments; this figure is inverted. (See p. 34.)

Plate II.

Figs. 7–9. *Columnastræa bicoronata*, sp. nov. Uradu Limestone, near Uradu, south of Dobar, and in the Duban. Coll. Mrs. Lort Phillips. Fig. 7 = part of the surface of a specimen from the Duban, × 2 diam.; fig. 8 = part of a horizontal section of a specimen from Uradu, × 2 diam.; fig. 9 = part of a horizontal section of a specimen from the Duban, × 2 diam. (See pp. 32–33.)

Fig. 10. *Columnastræa Phillipsiæ*, sp. nov. Uradu Limestone, Uradu. Coll. Mrs. Lort Phillips. Part of a horizontal section, × 3 diam. (See p. 33.)

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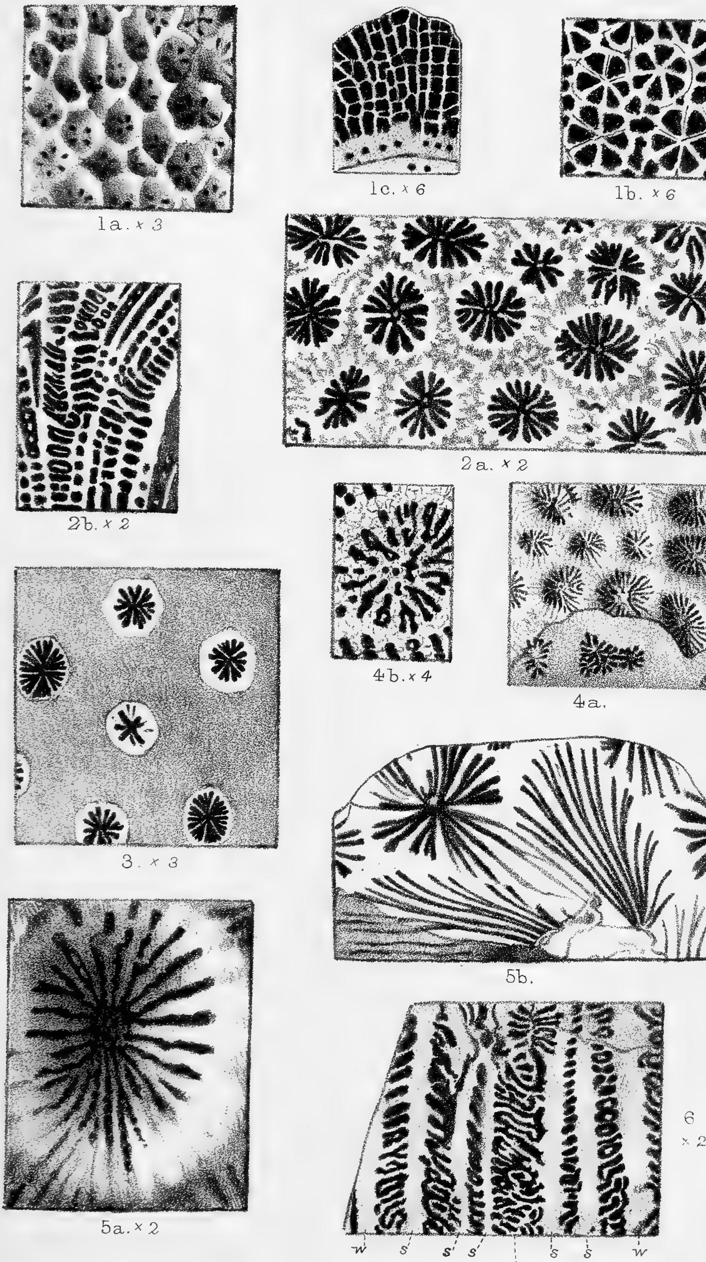
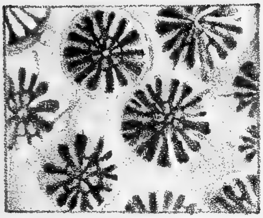
[1] [This probability is based on three lines of evidence: the agreement in direction of the movements which have caused the Aden Gulf and the Somali Plateau; the absence of Lower Kainozoic deposits in the Red Sea, except towards the north, where, as in the Gulf of Akaba, their fauna is of Mediterranean affinities; and the recent date of the separation of Arabia and Africa, as indicated certainly by zoological evidence, and probably by the local traditions. For the last see my 'Great Rift Valley,' 1896, chapts. xii & xiii.—December 22nd, 1899.]



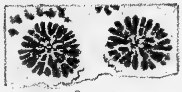
E. Drake del. et lith.

West, Newman imp.

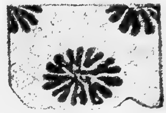
Corals from Somaliland.



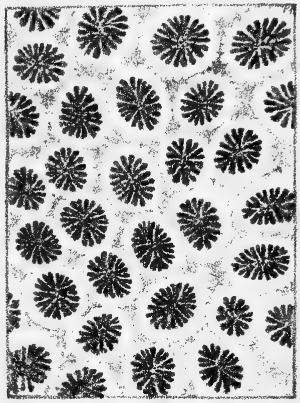
7. × 2



8. × 2



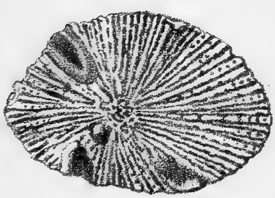
9. × 2



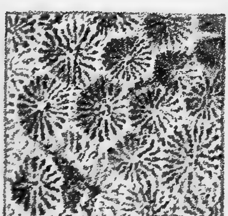
10. × 3

11a.

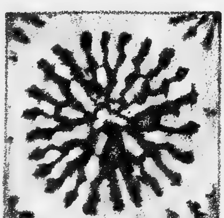
12 a. × 2



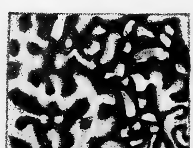
11 b.



13. × 2



14. × 6



12 b. × 6

E. Drake del. et lith.

West, Newman imp.

Corals from Somaliland.

Fig. 11. *Metethmos asymmetrica*, sp. nov. Dobar Limestone, Dobar. Coll. Mrs. Lort Phillips. a = side view; b = horizontal section, both nat. size. (See p. 36.)

12. *Litharæa Colæ*, sp. nov. Uradu Limestone, Uradu. Coll. Mrs. Lort Phillips. a = part of the upper surface, × 2 diam.; b = a horizontal section of the same, × 6 diam. (See p. 37.)

Figs. 13 & 14. *Litharæa Parkinsoni*, sp. nov. Cherty Limestone, Somali Plateau. Coll. Mr. F. B. Parkinson. Fig. 13 = part of the surface, × 2 diam.; fig. 14 = section across one corallite of another specimen, × 6 diam. (See p. 37.)

Discussion.

Dr. Blanford said that a slight acquaintance with the geology of a tract of country 500 miles away from Somaliland was scarcely sufficient to justify him in commenting on this paper, which was a valuable addition to our geological knowledge of North-eastern Africa. The Author was probably right in regarding the Gulf of Aden as of post-Eocene origin, but the evidence adduced of the post-Eocene elevation of the Somali plateau did not absolutely preclude the possibility that the depression forming the present Gulf of Aden existed earlier. The opening of the Straits of Bab-el-Mandeb appeared to be of very late geological date, perhaps Pleistocene.

Mr. Walcot Gibson said he was sure that all interested in African geology would be indebted to the Author for bringing to our notice the existence of Lower Tertiary beds with a Tertiary fauna on the plateau of Somaliland. A few undoubted facts fixing the age of sediments in East Africa are exceedingly welcome.

Mr. G. C. Crick asked the Author whether the *Pseudodiadema* from Bihin threw any light on the age of the Bihin limestone, as the cephalopoda from the same locality appeared to indicate the presence of an horizon somewhat younger than Bathonian.

The Author, in reply, said that he thought the *Pseudodiadema* gave no more precise information as to the age of the Bihin limestone than that it was approximately Callovian or Bathonian. The only Tertiary marine fossils from the Erythræan Rift-valley of which he knew were a doubtful echinid from Nyasaland, and the Miocene fossils from the northern part of the Red Sea. The absence of Kainozoic marine deposits, except Pleistocene, in the southern part of the Red Sea, and the fact that those of the northern part of that area are of the Mediterranean, and not of the Indian Ocean type, rendered it probable that the Aden Gulf was formed by the same series of movements as those which formed the Somali scarp.

5. *On the* Occurrence *in* British Carboniferous Rocks *of the* Devonian Genus *Palæoneilo*, *with a* Description *of the* New Species *P. carbonifera*. By Dr. Wheelton Hind, B.S., F.R.C.S., F.G.S. (Read December 6th, 1899.)

The genus *Palæoneilo* was established by Hall for certain Nuculiform shells from the Devonian beds of New York. He selected as the type *Palæoneilo constricta*, which had hitherto been referred to the allied genus *Nuculites* by Conrad.

The diagnosis of the genus was as follows:—

'Nuculiform shells, transversely ovate or subelliptical, the posterior end often subrostrate, with a more or less defined sulcus along the umbonal slope. Cardinal line arcuate. Surface marked with striæ of growth, which are often lamellose and elevated into concentric ribs. Hinge furnished with a row of regular small transverse teeth, which is sometimes interrupted beneath the beak by a change in the direction of the teeth, or by several oblique teeth. Ligament external, contained in a shallow and narrow groove along the cardinal border. Muscular scars not strongly impressed, situated below the extremities of the hinge-line. Pallial line simple.' Hall referred twenty species to this genus.

The Nuculidæ are represented in Carboniferous rocks by the genera *Nucula*, *Nuculana*, and *Ctenodonta*, and to these must now be added *Palæoneilo*. Two fine examples of this genus are in the Museum of Practical Geology, Jermyn Street, labelled 'Carboniferous Shale (bottom of Yoredale Shale), beck south of Hammerton Hall, Slaidburn, Yorkshire,' which I think means that the shells occur above the massif of Mountain Limestone, at which horizon the allied genus *Ctenodonta* also occurs.

It is therefore curious that a genus so well developed in Devonian times should appear at the top of the Carboniferous Limestone Series, there being no trace of its existence in intermediate beds. It is also noteworthy that the species attains considerable size, and is remarkably well developed, the shell possessing all the distinctive characters of the genus.

Genus Palæoneilo, Hall, 1870.

1842. *Nuculites*, Conrad, Journ. Acad. Nat. Sci. Philad. vol. viii, p. 249.

1858. *Leda*, Stevens, Amer. Journ. Sci. ser. 2, vol. xxv, p. 262.

1870. *Palæoneilo*, Hall, 'Prelim. Notice Lamellibr. N. Y.' pt. ii, p. 6; 1882. Whitfield, Ann. N. Y. Acad. Sci. vol. ii, p. 217; 1885. Hall, Pal. N. Y. vol. v, pt. 1, Lamellibr. ii, p. xxvii; 1887. Fischer, 'Man. de Conchyl.' p. 984; 1888. Œhlert, Bull. Soc. géol. France, ser. 3, vol. xvi, p. 653.

1895. *Ctenodonta*, pars, Beushausen, Abhandl. Königl. Preuss. Geol. Landesanst. ser. 2, pt. xvii, p. 65.

Observations.—The generic diagnosis has been given above, and to it I have nothing to add. *Palæoneilo* differs from *Nucula* and *Nuculana* in possessing no internal cartilage-pit, situated beneath the umbo, and between the anterior and posterior lines of teeth. From *Nuculites* it also differs by having the row of hinge-teeth

interrupted below the umbo, and by having no shelly process (the clavicle) separating the anterior adductor muscle-scar from the rest of the valve. *Ctenodonta*, however, is much more nearly related to *Palæoneilo*, but the former is nearly equilateral, and has no vertical comb-like hinge-teeth just below the hinge, neither does it possess the characteristic radiating sulcus, on the dorsal slope, or the well-marked escutcheon.

Beushausen has, however (*op. supra cit.*), referred all the Devonian shells of Rhenish Prussia to *Ctenodonta*, considering that *Palæoneilo* is nothing more than a subgroup of that genus. Œhlert (*op. supra cit.*), on the other hand, considers *Palæoneilo* to be generically distinct from *Ctenodonta*. Whidborne[1] refers certain shells to *Ctenodonta* (*Palæoneilo*).

The following is a formal description of the species to which I give the name *Palæoneilo carbonifera*.

PALÆONEILO CARBONIFERA, sp. nov. (Figs. 1–3, p. 48.)

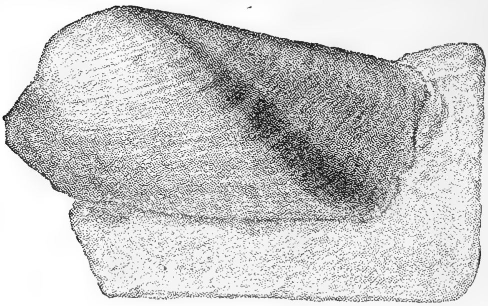
Specific characters.—Shell of more than medium size, transversely ovate-rhomboidal, oblique, very inequilateral, gibbose. The anterior end is very small, gibbose, narrowed from above downward, with its margin rounded. The inferior border is rounded in front, almost straight posteriorly, forming a well-marked, slightly obtuse, but gently rounded angle with the posterior border. The latter margin is sinuous, convex above and concave below, the upper portion being the larger. The postero-superior angle is very wide. The hinge-line is arched, though the upper margin of the valve, posterior to the umbo, appears straight, and is somewhat depressed as it passes backward.

The umbones are large, tumid, incurved, and markedly twisted forward, contiguous and elevated, placed very far backward, and much excavated in front, but there is no true lunule. Passing downward and backward from the umbo obliquely to the postero-inferior angle is a blunt ridge which separates the dorsal slope from the rest of the valve. In front of the oblique ridge the valve is convex from above downward, and below backward, the dorso-ventral curvature being much greater than the transverse. There is a marked flattening, or broad shallow sinus, in front of the ridge. Immediately above and posterior to the ridge is a well-marked sulcus, commencing as a narrow groove just behind the umbo, but becoming deeper and broader as it approaches the posterior margin, to the concavity in the border of which it corresponds. Above this radiating sulcus the dorsal slope swells, so as to become markedly convex, but this convexity is separated from the upper margin of the valve by a shallow groove forming the outer limit of the escutcheon. The escutcheon is large and well marked; it is bounded internally by the narrow elongate groove for the external ligament, and externally by a slight curved ridge which starts from the umbo, and, curving outward, at first gradually approaches the margin, coalescing with it near the postero-superior angle.

[1] Monogr. Palæont. Soc. 'Devonian Fauna,' vol. iii, pt. i (1896) p. 98.

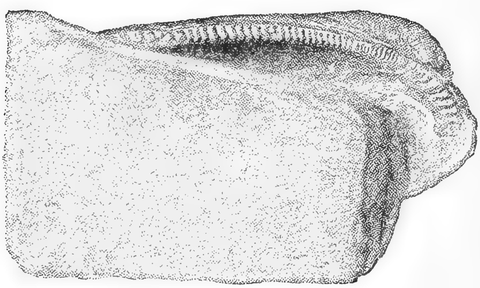
PALÆONEILO CARBONIFERA, sp. nov.

Fig. 1.



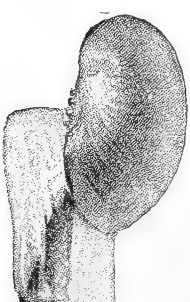
[A left valve, a little incomplete at the postero-superior angle.]

Fig. 2.



[The same valve, showing the hinge-plate and escutcheon.]

Fig. 3.



[The same specimen, showing the degree of incurvature of the umbo and the dorso-ventral curve of the valve.]

Note.—All the figures are of the natural size.

The anterior part of the lower margin is much incurved, but gradually, being twisted outward on itself, becomes flattened and depressed in its posterior half.

Interior.—The muscle-scars and pallial line have not been observed. The hinge is multidenticulate, and the hinge-plate is much thickened. Anteriorly there are several (seven) large oblique simple teeth, becoming larger as they approach the front, with the exception of that one which is placed most anteriorly. These pass just behind the umbo into a number of vertical, much smaller, closely-placed, comb-like, simple teeth, which extend for some distance behind the umbo, and then gradually become larger and oblique in position, each tooth slanting downward and forward, and becoming more widely separated from its neighbour, the row of teeth extending to within a small distance of the postero-superior angle.

Exterior.—The surface is ornamented with fine close lines of growth, which follow accurately the contour of the shell, being oblique to its long axis, and are more marked in the region of the umbo, and on the dorsal slope, where they may become sub-imbricate.

Dimensions.—The specimen figured measures antero-posteriorly 57 mm., and dorso-ventrally 27 mm.; convexity of valve = 12 mm.

Locality.—England, in shales above the main mass of limestone in the beck, south of Hammerton Hall, Slaidburn (Yorkshire).[1]

Observations.—*Ctenodonta* (*Palæoneilo*) *lirata* (Phill.), from the Devonian of Baggy, has much the same kind of surface-marking as *P. carbonifera*, but differs entirely in shape; indeed, this species is quite distinct from any of the shells belonging to the same genus, either from European or American Devonian localities. I am unable to say anything about the fauna associated with *P. carbonifera* at present, but beds of shale on presumably the same horizon at Whitewell, a few miles farther south, contain the following fossils:—*Ctenodonta sinuosa*, *Nuculana attenuata*, *Parallelodon semicostatus*, *Modiola* sp., *Glauconome*, *Fenestella* sp., *Retipora pluma*, Phill., *Glyphioceras spirale*, and *Orthis Michelini*.

Discussion.

Mr. Walcot Gibson said that he was pleased to see that the Author found opportunity, amidst a busy professional life, to add from time to time to our knowledge of the lamellibranch fauna of the Carboniferous system. The absence of a *Palæoneilo* from the lowest beds of the Carboniferous Limestone was possibly accounted for by the really little palæontological work that had as yet been done, considering the great development of the Lower Carboniferous rocks in England and Wales. Further research would no doubt fill up many gaps.

Mr. R. S. Herries, Dr. G. J. Hinde, the Rev. G. F. Whidborne, and Mr. Strahan also spoke.

[1] [The specimen was collected and labelled by Mr. Gibbs, late fossil-collector to the Geological Survey.]

6. *On some* Remarkable Calcisponges *from the* Eocene Strata *of* Victoria (Australia). By George Jennings Hinde, Ph.D., F.R.S., F.G.S., (Read November 22nd, 1899.)

[Plates III–V.]

About two years ago Mr. T. S. Hall, M.A., of the University of Melbourne, forwarded to me, for examination and description, some small specimens of calcisponges which he had collected in different localities in the southern part of the Colony of Victoria. The sponges were found together with numerous species of bivalve mollusca, brachiopoda, fragmentary polyzoa and echinoid-tests, in beds of loose materials, sandy, clayey, and calcareous, which have been regarded, mainly on the evidence of the mollusca, as of Eocene age. The sponges are all fairly perfect as regards outer form, but in the great majority the spicular structure had been much altered in the fossilization, though sufficient was preserved to lead to the belief that they were new species. In one specimen, however, which came from 'Griffin's Farm' on the lower reaches of the Moorabool River, north of Geelong, the structure both of the exterior and interior of the sponge was in so unusually favourable a state of preservation that even the smallest spicules could be isolated and examined, and the character of the skeletal mesh could be ascertained with as much precision as in recent sponges. The structural features of this specimen, as will be seen from the description, are distinct from those of any fossil calcisponge hitherto described; and it resembles, in the peculiar form of the skeletal spicules and the firmness with which they are welded together to form the mesh, the remarkable calcisponge *Petrostroma Schulzei*, described recently [1] by Prof. L. Döderlein, from the Japanese Sea, which has been placed by Dr. Rauff [2] as a distinct order of calcisponges, the Lithonina, in contrast to all other calcisponges, living and fossil, in which the spicules of the skeleton are regular in form and not fixedly attached together. At my request Prof. Döderlein very kindly supplied me with some fragments of this new sponge, which he has fully described and figured, and I have thus been enabled directly to compare the fossil with the recent representative of the new order.

In addition to the specimens sent to me by Mr. Hall, I describe here also (pp. 60–61) some very diminutive but perfect examples of calcisponges presented to me by Mr. B. W. Priest, who picked them out of some washings of polyzoa from beds at Mount Martha, Mornington, near Melbourne, which are of the same geological age as those already mentioned. These small sponges, though differing in some details, belong likewise to the same group as the recent

[1] Verhandl. d. Deutsch. Zool. Gesellsch. auf d. 2ten Jahresversammlung (1892) p. 143; Zool. Jahrb. vol. x (1898) pp. 15–32 & pls. ii–vi.

[2] Palæontographica, vol. xl (1894) p. 204.

Petrostroma and the 'Griffin's Farm' specimen. My warmest thanks are due to Mr. Priest for placing at my disposal for description all the specimens that he possessed.

I propose, first, to describe in some detail the characters of the 'Griffin's Farm' specimen, which is placed as the type of a new genus, *Plectroninia*, and then to follow with a description of the other forms.

Plectroninia[1] *Halli*, gen. et sp. nov. (Pl. III, figs. 1–83; Pl. IV, figs. 1–11.)

The type of the genus is turbinate in form, the base is blunted and free, the lateral surface somewhat corrugated, and the summit gently convex. It measures 16 mm. in height by 18 mm. in its greatest width, which is just below the summit. It is now quite free from matrix, except a small portion of the upper surface which is covered with a greenish sandy clay containing subangular quartz-grains. The summit is of a brownish-grey, while the lateral surface is grey to silvery white; the last-named tint, however, is only shown where a too close application of a cleaning instrument has removed the stained outer layer. The sides of the sponge were originally covered by a spicular dermal layer, only in part preserved: no traces of pores or canal-apertures could be detected in it. This dermal layer did not apparently extend over the summit, which is formed of the main spicular skeleton with open interspaces and the apertures of excurrent canals. For a short distance below the upper surface, the mesh-interspaces and canals are partly filled with the fine granular matrix, in which are some foraminifera (*Globigerina*, *Rotalia*, *Spiroloculina*, etc.) and rarely diatoms showing their minute structure.

To study the interior structure, the sponge was sawn through in a vertical direction from summit to base; from one moiety thin slices were cut off and mounted for the microscope in Canada balsam, and fragments of the dermal layer were similarly mounted in balsam. The interior mesh of the sponge, with the exception of the stained portion near the summit, is of a dull white; the mesh-interspaces and the canals are quite free from any infilling, save for wisps and irregular bands of loosely-arranged, delicate spicules, apparently in the same position as during the life of the sponge. The interior skeleton is of a firm, resistant character, not unlike that of a recent Lithistid.

Dermal Layer.

The dermal layer or cortex, as already mentioned, is limited to the lateral surface of the sponge; it is thin, the outer surface mostly smooth, but in places wrinkled and of a silvery white appearance. This layer rests directly on the main skeletal mesh, except in the basal portion of the sponge, where it passes into a subdermal layer of

[1] πλῆκτρον, spur; ἴς, ἰνός, fibre.

peculiar spicules described below. Owing to its delicate character the dermal layer can be seldom shown in microscopic sections, but fragments of it may be readily flaked off with a needle and mounted for examination. It appears to consist mainly of elongate, smooth, nearly cylindrical rod-like spicules, pointed, either lance-shaped or styliform, at both ends (Pl. III, figs. 43 & 44). On the exterior surface these spicules are disposed generally parallel in the direction of the length of the sponge, thus forming a sort of surface-thatch (Pl. IV, fig. 1). The spicules are not attached together in any way, and they may be readily separated by treatment in water with a camel's-hair brush, but they are so fragile that it is rare to obtain any entire; the longest fragment measured 0·61 mm. by 0·01 mm. in thickness.

The inner surface of the dermal layer, in contact with the main skeleton, is very uneven, with irregular ridges and intermediate furrows, and it is penetrated at irregular intervals by small holes with circular apertures from 0·05 to 0·075 mm. wide. At first these holes were supposed to be connected with inhalant pores, but in reality they appear to be due to the free apical rays of the mesh-spicules which had penetrated into the dermal layer, and had left their moulds when this was removed from the sponge.

The inner portion of the dermal layer also consists of cylindrical spicules, with pointed ends, smaller than those of the exterior, and, unlike these latter, loosely intermingled without arrangement.

In addition to the simple rod-like spicules, the inner portion of the dermal layer contains a subordinate number of minute three- and four-rayed spicules of various forms, which appear to be common also to the basal layer. The simplest of these are three-rayed spicules of types common in recent calcisponges generally (Pl. III, figs. 4–15). The spicular rays are usually straight and smooth, tapering very gradually. Some are regular, having the rays of equal length; others are sagittate: while in others all the rays are unequal. Rarely the rays are curved (Pl. III, fig. 15), with an occasional spine. The rays of these spicules vary in length between 0·004 and 0·225 mm.

The peculiar three-rayed spicules, known as 'tuning-fork' spicules, in which the paired rays are parallel to each other and the third ray extends in the opposite direction, forming the shaft of the fork, are present, but of somewhat rare occurrence (Pl. III, figs. 30–38). The paired rays are relatively short and terminate obtusely, and the shaft-ray is nearly cylindrical. These spicules are frequently eroded and fretted, in marked contrast to the smooth glistening surfaces of other spicules, equally as minute and delicate, with which they are associated. The forked rays of these spicules range between 0·016 and 0·04 mm. in length, and are about 0·004 mm. in width, while the shafts are from 0·02 to 0·17 mm. long, but it is doubtful whether any are entire.

This type of spicule [1] was first recognized in a recent calcisponge from the Australian seas; it has since been found in fossil Pharetron

[1] Bowerbank, 'Monogr. of Brit. Spong.' Ray Soc. vol. i (1864) p. 268 & pl. x, fig. 237.

calcisponges from the Cretaceous and Jurassic rocks of this country,[1] and it occurs also in the recent *Petrostroma Schulzei*,[2] Döderl. from the Japanese Sea.

The minute four-rayed spicules of the inner portion of the dermal layer have stout, tapering rays: the facial are often curved, while the apical is straight, conical, and sometimes minutely spined (Pl. III, figs. 16–20, 22, 24). It is probable that some of these four-rayed forms may represent early stages of the skeletal mesh-spicules, seeing that the termination of the facial rays in some instances appears already in process of expansion (Pl. III, figs. 21, 27).

Basal Layers.

At the base of the sponge, and also at different levels or stages of its growth, there are thin layers of closely-arranged spicules extending transversely across the spicular mesh and the canals, and forming floors or platforms of the same contour as the summit of the sponge. In places these particular layers are accompanied by an outside layer of fine rods or needles similar to the dermal layer, but they also occur without these accessories. The basal layers are built up of small spicules, extremely variable in form, which are united together to make an intricate and closely-arranged mesh-work. Hardly any two of these spicules are alike, and the figures given of them (Pl. III, figs. 48–82) will convey a better idea of their remarkable diversity than any verbal description. They appear to be all four-rayed spicules, in which one ray, corresponding to the apical ray in the normal four-rayed calcisponge-spicule, is conical, pointed, and either smooth or partly covered with small prickles. The three other rays, the equivalents of the facial rays in normal spicules, are mostly unequal in length in the same spicule, straight or curved irregularly in a direction opposite to that of the apical ray; they scarcely taper, if at all, and they are usually armed with stout prickles or spines. In some instances these facial rays terminate obtusely (Pl. III, figs. 79, 81), but more frequently their ends are expanded so as to form flattened or concave facets with evenly rounded or lobate margins.

The spicules of the basal layers are of small size; the rays vary from 0·025 to 0·13 mm. in length, and from 0·01 to 0·02 mm. in thickness. Rarely, however, a larger form occurs in a free condition, which approximates in size and other features to the mesh-spicules (Pl. IV, fig. 9).

These spicules are united to form the meshwork of this basal layer by the close apposition of the terminal expansions of the facial rays of the spicules to the rays of proximate spicules, in much the same way as the mesh-spicules in the Lithistid genera *Doryderma*, Zittel, and *Lyidium*, O. Schmidt (Pl. III, fig. 83, & Pl. IV, figs. 2, 3).

[1] Hinde, Ann. & Mag. Nat. Hist. ser. 5, vol. x (1882) p. 199 & pl. xii; Monogr. Palæont. Soc. 'Brit. Foss. Spong.' pt. iii (1893) p. 214 & pl. xiv, fig. 1 *d*, p. 220 & pl. xv, figs. 3 *f*, 3 *g*.

[2] Zool. Jahrb. vol. x (1898) p. 20 & pl. iii, figs. 1–9.

The union is not of a fixed character like that of the mesh-spicules of the sponge, for by slight pressure the individual spicules may be separated without difficulty uninjured. The mesh is close and intricate, so that it is not easy to trace single spicules, but in some instances there seems to be a definite orientation whereby the pointed apical or free rays are directed upward (Pl. IV, figs. 2 & 3). In the case of the transverse platforms, the basal spicules are frequently attached to the much larger mesh-spicules as well as one to another.

Similar transverse layers or floors, indicating periodic stages of growth, have been noticed in other fossil calcisponges, and more particularly in species of *Lymnorella*,[1] but hitherto their spicular structure has not been recognizable.

Skeletal Mesh.

The main skeleton of the sponge is very firm and resistant; when seen under the microscope by reflected light, it appears to consist of stout, cylindrical, continuously anastomosing fibres of a rough, dull, glassy aspect, forming a close meshwork with oval, rounded, and elongated interspaces, and also enclosing definite canals. From the surface of the fibres, at intervals, sharply pointed spurs extend into the interspaces, and these are also partly occupied by loose wisps of simple rod-like spicules.

The structural details of the mesh-fibres can be seen only in thin microscopic sections mounted in Canada balsam. These show that the fibres consist of four-rayed spicules in which the apical ray is relatively very elongate, tapering to an acute point, and armed laterally with a few stout, horizontally projecting prickles (Pl. IV, figs. 4–8). The facial rays of the spicule, on the other hand, are short, robust, straight, or curved in a direction opposite to that of the apical ray; they do not taper as a rule, but terminate in flattened or concave expansions of a character similar to those of the spicules of the basal layer, described above. Exceptionally, however, one of the facial rays of a spicule is extended and tapers to a blunt end. The apical rays in these mesh-spicules range from 0·2 to 0·35 mm. in length, while the facial rays range from 0·1 to 0·18 mm., and they are about 0·05 mm. in thickness at the base. Neither in these comparatively large mesh-spicules, nor in any of the smaller spicules of this sponge, though their condition of preservation is so perfect, is there any trace of an axial canal: in this respect they differ markedly from fossil s i l i c e o u s spicules.

These mesh-spicules are united to form the fibres by the firm apposition and close fitting of the expanded terminations of their facial rays to the surfaces of adjoining spicules in much the same manner as the spicules of the basal layer, but they are, as a rule, oriented with much greater regularity, for the free tapering apical rays are disposed so that they point in a generally vertical direction towards the upper surface of the sponge (Pl. IV, figs. 4, 5, 6). As

[1] Monogr. Palæont. Soc. 'Brit. Foss. Spong.' pt. iii (1893) pp. 236, 237.

the fibres are reticulate, these apical rays do not always coincide in the same direction, and consequently their spur-like distal ends frequently project beyond the surface of the fibres into the mesh-interspaces.

In addition to the close union of the mesh-spicules by the apposition of the terminal expansion of their facial rays, they are further united and cemented together by the deposition of a calcitic layer, which envelops the mesh-fibres and binds together their constituent spicules in much the same manner as the spicules in the skeletal mesh of the Dictyonine Hexactinellids are united by an envelope of silica. In this calcisponge the common investment consists of a thin pellicle of calcite, the outer surface of which is covered with numerous minute blunted tubercles or acute prickles (Pl. IV, figs. 4–8). This pellicle does not seem to invest the fibres evenly throughout; it has a scabious appearance, as if formed in patches whose margins are in irregular contact and sometimes overlap. In cases where mesh-spicules stand out singly from the fibres they are not covered with this pellicle, the terminal points of the apical rays which project freely beyond the fibres are likewise free from it, and these points are always smooth and glistening, in contrast to the whiter and less transparent aspect of the portion of the spicules over which the pellicle extends.

In order to test the stability of the union of the spicules in the fibres, small fragments of the mesh were treated for a short time in dilute acetic acid until they were considerably reduced, and they were then washed and subjected to pressure under a cover-glass, with the result that the spicules generally gave no signs of separation, but broke up irregularly instead of parting where the junctions had originally taken place. In many cases the planes of contact, where the terminal expansions had clasped round adjoining spicules, could not be distinguished, and complete fusion had been effected at the point of union. The elongated apical rays, so conspicuous in the fibres, are also firmly welded to the surfaces of other spicules in the fibres with which they may be laterally in contact. In some exceptional instances, when the fibres are broken up with a needle, a spicular ray will disconnect from its original attachment without fracture (Pl. IV, fig. 7), and in this eventuality the ray has not been enveloped by the calcitic pellicle.

That the welding together of the spicules in the mesh-fibres cannot be attributed to the results of fossilization is shown by the fact that in the interspaces of the mesh are numerous minute spicules intermingled, yet perfectly free from attachment; and, further, the irregular spicules of the basal layer, though connected by clasping in the same way as the mesh-spicules, are not fused together, and readily separate without fracture.

The disposition of the spicules in the mesh is most favourably shown in vertical sections of the sponge (Pl. IV, figs. 4 & 5), while in transverse sections the canals are exposed, and the mesh-fibres appear to be closer and more confused than in the vertical sections

(Pl. IV, fig. 10). The upper surface of the sponge exhibits spicules of the same character as in the interior; the three facial rays are connected with those of adjacent spicules, so as to mark off small rounded or subangular interspaces, while here and there are distributed the larger rounded canal-apertures. The projecting apical ray of the spicules is short and inconspicuous at the surface.

In a small region near the base of the sponge the mesh is built up of more delicate spicules, and the interspaces are closer than in the rest of the skeleton (Pl. IV, fig. 11); with this exception the proportions of the fibres are fairly uniform, but they slightly tend to become thicker in the upper part of the sponge. Simple fibres, of a single spicular ray, are about 0·05 mm. thick, while those in which two or more rays overlap one another reach to 0·1 mm. in thickness.

In the interspaces of the skeletal fibres numerous slender spicules are distributed, either singly, in small aggregates, or in tufts or wisps, in which the spicules are generally parallel. These spicules are almost exclusively cylindrical or slightly fusiform rods, pointed at both ends, either smooth or having surfaces studded over with minute spines (Pl. III, figs. 39, 39 *a*, 46, 47). Some are exceedingly delicate, and yet as perfect as in recent sponges. They vary in length from 0·04 to 0·42 mm., and in thickness from 0·002 to 0·004 mm.

Of rare occurrence are straight, styliform, and pin-shaped spicules, with somewhat tumid heads, smooth surfaces, cylindrical or slightly tapering shafts, and pointed ends, which are either from the inner portion of the dermal layer or associated with the simple pointed rods of the mesh-interspaces (Pl. III, figs. 40–42). They measure from 0·13 to 0·2 mm. in length, and about 0·004 mm. in thickness.

Canal-system.

No definite incurrent pores or canals can be recognized in the skeleton; on the other hand there is a well-marked system of excurrent canals, which take their rise in the lower portion of the sponge and extend in a generally vertical or radiate direction to open out at the summit (Pl. III, fig. 1 *a*). Some canals also appear at the side of the sponge, near the upper margin of the dermal layer, and are continued as open furrows over the summit-edge. The walls of the canals are formed by the ordinary spicular fibres, and they are in free communication with the interspaces of the mesh. Numerous free cylindrical spicules occur within the canals, just as in the mesh-interspaces; in places they are so abundant as to give an idea that they may have formed an inner lining to the canal-walls. The canals range from 0·2 to 0·5 mm. in width. In the central area of the sponge-summit they are about their own diameters apart, but apparently at somewhat wider intervals towards the margins.

The Relations of *Plectroninia* to other Calcisponges.

In the principal characteristic feature, the organic fusion or welding together of the spicules of the skeletal mesh, this genus bears a distinct relationship to the recent *Petrostroma Schulzei*, Döderl. the only calcisponge, recent or fossil, in which up to the present a definite fusion of the skeletal spicules has been shown to take place, and there can be no doubt that it will come under the group of Lithonina, proposed by Rauff to include sponges with this character. At the same time there are considerable differences between *Petrostroma* and *Plectroninia*. To take first the spicules of the skeletal mesh (stützskelet), these in *Petrostroma* have their facial rays[1] (cladiske) usually curved and tapering to a blunt extremity, whereas in *Plectroninia* they are truncate with expanded ends (Pl. IV, figs. 7 & 8), and it is only in very exceptional instances that a facial ray resembles those of the recent sponge. With this difference in the form of the facial rays there is also a corresponding variation in their mode of union, which in *Petrostroma* appears to be effected by lateral fusion wherever they are in contact with adjacent rays, instead of by a close fitting of the terminal facets of the rays and subsequent fusion. Again in *Petrostroma* the skeletal fibres have the form of relatively thick balks,[2] connected transversely by minute spinous spicules, which radiate to the surface of the sponge, whereas in our sponge the fibres are regularly reticulate, and not pronouncedly radial in direction. Moreover, the canal-system in *Plectroninia* differs markedly from that of *Petrostroma*, and the characters of the dermal and basal layers in the two genera are also unlike.

There are two other genera of fossil calcisponges known to me in which the spicules are fused together like those of *Plectroninia* and *Petrostroma*: one is *Bactronella*,[3] Hinde, which will be referred to later on (p. 59), and the other *Porosphæra*,[4] Steinmann, placed by this author as a Hydrocoralline allied to *Millepora*. The evidence of the affinity of this genus to the Lithonina I hope to publish shortly, and will now only remark that it is sufficiently distinct from *Plectroninia* to allow of the validity of this latter.

Prof. Döderlein[5] has commented on the striking general resemblance between the skeletal fibres of *Petrostroma* and those of genuine Pharetron calcisponges, and also on the occurrence, in both groups of sponges, of the very specialized 'tuning-fork' spicules; but, on the ground of the independent character of the spicules in the fibres of the Pharetrones as compared with their fused condition in *Petrostroma*, he concludes that these two kinds of sponges have nothing to do with each other. The likeness of *Plectroninia* to

[1] Zool. Jahrb. vol. x (1898) pl. ii, figs. 31–34.
[2] *Ibid.* pl. iv, fig. E.
[3] Cat. Foss. Spong. Brit. Mus. (1883) p. 205.
[4] Palæontographica, vol. xxv (1878) p. 120.
[5] Zool. Jahrb. vol. x (1898) p. 28.

Cretaceous and Jurassic Pharetrones is yet more pronounced, for the skeletal fibres of this sponge are more distinctly anastomosing, and reticulate rather than radial in their arrangement, and until examined under the microscope they could hardly, if at all, be distinguished from those of many Pharetrones. Hitherto the independent character of the spicules in the Pharetron fibres has been generally accepted; but now that the occurrence of organic fusion has been proved in the case of these Lithonina, there is room for suspecting that it may have also taken place in the fibres of some of the Pharetrones. A renewed examination of my microscopic sections of Pharetrones, in the light of the new discoveries, leads me to think that there is very fair evidence that fusion may have occurred in the fibres of such sponges as *Sestrostomella rugosa*,[1] Hinde, and *Holcospongia floriceps*[2] (Phill.), in which the rays of large spicules extend longitudinally in the central axis of the fibres and are closely enwrapped by smaller filiform spicules. These larger axial spicules are four-rayed, one ray is relatively short and pointed, the others are elongated, do not taper, and apparently are truncate or slightly expanded at their ends. These seem to be closely fitted to adjoining spicules, and resemble, in their form and mode of union, the facial rays of the spicules in the fibres of *Plectroninia*. In transverse sections of the fibres of *Sestrostomella rugosa* the smaller spicules[3] appear also to be clasped intimately to the larger, but whether this has been accompanied by fusion or cementation is not definitely shown in the microscopical sections at my disposal. The question whether the constituents of the fibres in some of the Pharetrones are organically cemented together or independent cannot be decided at present, but it seems to me probable that eventually several genera in this family will have to be placed with the Lithonina.

Diagnosis of *Plectroninia*, gen. nov.

Turbinate or rounded sponges, sessile or with a short pedicel, the sides covered wholly or in part with a dermal layer of simple pointed rods, styliform and pin-shaped forms, normal three- and four-rayed and 'tuning-fork' spicules, free from each other, and irregularly intermingled, except on the outer surface, which is formed mainly of simple rods disposed parallel with each other. At the base of the sponge, and also forming floors at different levels, are thin layers consisting of four-rayed spicules of extremely irregular and varied forms, which are attached together by the clasping of the expanded termination of their facial rays to the surfaces of adjacent spicules, but they are not apparently cemented

[1] Ann. & Mag. Nat. Hist. ser. 5, vol. x (1882) p. 198 & pl. x, fig. 6, pl. xii, figs. 1–15; see also Catal. Foss. Spong. Brit. Mus. (1883) p. 188 & pl. xxxv, figs. 4, 4 *a*–4 *d*.

[2] See Palæont. Soc. Monogr. 'Brit. Foss. Spong.' pt. iii (1893) p. 226 & pl. xvi, figs. 6–6 *c*, pl. xvii, fig. 2.

[3] Ann. & Mag. Nat. Hist. ser. 5, vol. x (1882) pl. xii, fig. 2.

or grown together. The main skeleton of the sponge is of reticulate anastomosing fibres, built up of four-rayed spicules in which the apical ray is elongate, tapering and pointed, usually definitely orientated and frequently projecting, spur-like, beyond the fibres, into the mesh-interspaces. The facial rays are straight or curved, with truncate or expanded ends, which are not only closely fitted to the surfaces of adjoining spicules, but firmly cemented or fused as well. The fibres are invested with a calcitic pellicle, having a minutely spined outer surface. Slender rod-spicules are abundantly distributed in the interspaces of the mesh. A system of excurrent canals extends from the lower portion of the sponge in a generally vertical direction and open at the summit.

The characters of the type-species, *P. Halli*, are given in the foregoing description. The specific name is in honour of Mr. T. S. Hall, M.A., of Melbourne University, to whom I am indebted for the opportunity of studying this unique form.

In addition to the typical example there occur, in the collection of sponges sent me by Mr. Hall from beds of corresponding age at Flinders (Victoria), some small specimens which probably belong to this species; but, owing to the nearly complete obliteration of their spicular structure, they cannot be fully identified. The sponges in question are simple, rounded or turbinate, the base flattened or supported on a short blunt pedicel (Pl. III, figs. 2 & 3). They are from 6 to 10 mm. in diameter. Thin bands of dermal layer are present near the base, and transverse platforms are shown in the interior. The disposition of the mesh-fibres and the canals is the same as in the type of the species, but no comparison of the spicular structure can be made beyond that rarely the spined apical ray of a mesh-spicule is distinguishable.

Distribution.—The type-specimen is from Eocene clays[1] exposed in the banks of the Moorabool River at Griffin's Farm, north-west of Geelong; also from Polyzoal Limestone[2] of Eocene age at Flinders (Victoria). Collected by Mr. T. S. Hall.

Genus *Bactronella*, Hinde, 1883.
emend. Catal. Foss. Spong. Brit. Mus. p. 205.

This genus was proposed to include some small fossil calcisponges of Jurassic age, which had been placed as polyzoa under *Ceriopora clavata*,[3] Goldfuss. The microscopic structure of the specimens on which the genus was based was too imperfect to allow of a proper diagnosis; it was seen to differ from that of Pharetron calcisponges, and the genus was regarded as *incertæ sedis* until its characters were more clearly ascertained. The discovery of some well-preserved

[1] See Hall & Pritchard, 'Notes on the Lower Tertiaries of the Southern Portion of the Moorabool Valley' Proc. Roy. Soc. Vict. n. s. vol. iv (1891) p. 9; also 'Geology of the Lower Moorabool' *ibid.* n. s. vol. x (1897) p. 43.

[2] Rep. Austral. Assoc. Adv. Sci. vol. vi (Brisbane, 1896) p. 348.

[3] 'Petref. German.' pt. i (1833) p. 36 & pl. x, figs. *c–f* (non *a*, *b*).

sponges from the Eocene of Australia, evidently of the same generic type as *Bactronella pusilla*, Hinde, now enables me to give the following definition of the genus:—

Sponges usually small and simple, varied in form, rod- or club-shaped, rarely branching, conical, hemispherical, sessile, or with a short pedicel, free or attached, or sometimes encrusting. The outer surface is partly or entirely covered with a dermal layer; and there is also a basal layer of irregular four-rayed spicules, with the apical ray free and the facial rays forming a meshwork by the clasping together of the expanded ends of the rays, just as in *Plectroninia*. The spicules of the main skeleton are likewise of the same form, and firmly fixed together by the fusion of their facial rays, as those in *Plectroninia*. They are disposed in such wise that the free or partly free apical rays radiate upward and outward to the surface of the sponge; and they are united transversely by small spicules crossing the interspaces. The spicules bound minute radial canals which open directly on the sides and summit of the sponge.

This genus is intermediate in character between *Plectroninia* and *Petrostroma*. The spicules of the basal layer and of the main skeleton resemble in form, and in their mode of union with each other, those of the former genus, while in the radiate arrangement of the skeleton, the small transverse spicules, and the radial canals, there is great similarity to the latter. The apical rays of the skeletal spicules are not so completely fused as in the balks of *Petrostroma Schulzei*, and in some instances they are nearly free.

Bactronella parvula, sp. nov. (Pl. V.)

Sponges diminutive, simple, pear-shaped or subcylindrical, with rounded summits, encrusting other organisms, such as fragments of polyzoa or detached spines of echinoderms (Pl. V, figs. 1–4). They range in size from 2 to 4 mm. in length, and from 1·2 to 1·5 mm. in thickness.

The outer surface of the sponge is dotted over with the rounded apertures of the radial canals, which are from 0·1 to 0·12 mm. in width; their margins are formed by the three facial rays of four-rayed spicules, and the fourth or apical ray projects radially outward beyond the general surface of the sponge, thus giving it a spinous appearance when viewed under the microscope (Pl. V, figs. 1–4, 16). The radial canals are very short tubes, corresponding to the thin wall of the sponge.

The basal layer in these sponges is developed in direct contact with the foreign body over which they grow: in one sense it is in the interior of the sponge, and is not exposed to view until a section is made through the sponge. It consists of irregular four-rayed spicules: the facial rays, short and truncate, being often armed laterally with minute prickles, the apical rays pointed and free (Pl. V, figs. 9, 12–14). These spicules are connected by inter-clasping in the same manner as in *Plectroninia*, and apparently

they are not fused together. The spicular rays are from 0·025 to 0·05 mm. long, and about 0·01 mm. thick. In addition to the irregular spicules, there are in the basal layer a few simple three- and four-rayed spicules, having the facial rays approximately in the same plane (Pl. V, figs 5–8).

Neither simple rod-spicules nor tuning-fork spicules have been observed in the basal layer or in any other part of the sponge.

The four-rayed spicules of the main skeleton have the facial rays disposed in tripodal form; they are short, of nearly equal thickness throughout, with obtuse or expanded terminations; they are from 0·06 to 0·13 mm. in length, and about 0·025 mm. in thickness (Pl. V, figs. 15, 17–19). They are connected together by interclasping and by fusion as well. The apical rays gradually taper to a delicate point; they are, when complete, distinctly longer than the facial rays. Near the outside of the sponge these apical rays are free and project outward; in the interior of the sponge-wall they are connected transversely, by peculiar small four-rayed spicules, to adjacent apical rays. These connecting spicules (Pl. V, figs. 9, 12, 13) have two of the facial rays in one line; they are usually furnished with lateral prickles, and they terminate obtusely or expanded. They appear to be often fused as well as intimately fitted to the apical rays of the main skeletal spicules, and they give the appearance of lattice-bars crossing the radial lines of the skeleton (Pl. V, fig. 15). Similar connecting spicules are well marked in *Petrostroma Schulzei*.[1]

These sponges are scarcely, if at all, affected by fossilization, for the spicules are as bright and glassy as those of recent forms, and their finest details are preserved. The surfaces of the spicules of the basal layer and of the younger skeletal forms are smooth and even, while in the mature skeletal spicules the surface is covered with minute tubercles similar to the investing pellicle of the mesh-fibres in *Plectroninia Halli*. Some of the larger skeletal spicules are penetrated thickly in all directions by the minute interlacing borings of an alga (?) in much the same way as the skeletal tissues of recent and fossil corals.

Distribution.—These small forms were discovered in a collection of polyzoa from Mount Martha or Mornington, by Mr. B. W. Priest, who recognized them as sponges and submitted them to me for examination. Mr. T. S. Hall, of Melbourne, informs me that the Mount Martha or Mornington beds are well known for their richness in fossils; they are situated about 30 miles from Melbourne. Only a small outcrop, a few chains in length, is now to be seen. The late Sir Frederick M'Coy called the beds Upper Eocene at first, and afterwards Oligocene. Prof. Ralph Tate, of Adelaide, has furnished detailed evidence of their Eocene age, and his view on this point is now generally regarded as correct.

[1] Zool. Jahrb. vol. x (1898) p. 25 & pl. ii, figs. 19–25, pl. iii, figs. 20, 21, 23–25, pl. iv, fig. E.

Bactronella australis, sp. nov. (Pl. V, figs. 12–19.)

Sponges small, of various forms, club-shaped, conical, rounded or hemispherical, either supported on a short pedicel, sessile with flattened bases, or deeply concave. A small specimen is 5 mm. in height by 5 mm. in width, the largest 13·5 mm. by 10 mm. in width. The body of the sponges is frequently hollowed out by tubes and chambers, probably due to some boring organism. The sponges are now infilled with calcite, and their spicular structure is very imperfectly preserved.

The entire surface of the sponges is covered with a smooth, thin dermal layer, which conceals the apertures of the radial canals, but the spicular structure cannot be recognized. A vertical section shows radial lines extending from the basal to the outer surface of the sponge; these lines are from 0·08 mm. to 0·1 mm. apart, and they appear to be mainly formed of relatively stout apical rays of spicules arranged so as to overlap each other. The rays are straight, elongate-conical, from 0·2 to 0·35 mm. in length and about 0·08 mm. in thickness at the base (Pl. IV, fig. 19). The facial rays of these spicules can be seldom distinguished in sections. The lines of the apical rays are connected by numerous transverse bars; probably they represent small spicules of the same character as in the preceding species. No indications of detached spicules have been preserved. The surface beneath the dermal layer shows the minute rounded apertures of the radial canals, about 0·09 mm. in width; they are bounded by the facial rays of spicules fused at their points of contact with each other (Pl. IV, fig. 18). The apical rays of the spicules near the exterior do not seem to penetrate the dermal layer.

This species differs from *Bactronella parvula*, in its habit of growth, the complete covering of dermal layer, and the larger size of the spicular rays. No comparison in other structural details is possible, on account of the imperfect preservation of the specimens.

Distribution.—Not uncommon in a limestone-rock mainly composed of fragments of polyzoa with echinoid-tests and brachiopoda, shown in a small cliff-section at Flinders (Victoria). The beds overlie the 'Older Volcanic' and are regarded as of Eocene age. Collected by Mr. T. S. Hall, M.A.

Tretocalia[1] *pezica*, gen. et sp. nov. (Pl. IV, figs. 20–29.)

Sponges of small size, simple, cup-shaped, subcylindrical or rounded, with a cup- or funnel-shaped cloaca, their bases flattened or variously curved, and concave where the sponge has been attached to foreign bodies. Rarely is a dermal layer preserved; where present it is restricted to the base and to a narrow band round the side. The rest of the surface exhibits numerous rounded canal-apertures and minute irregular mesh-interspaces. The sponge-wall s moderately thick, the summit convex, with well-defined margins

[1] τρητός, pierced through; καλιά, a bird's-nest.

round the cloaca. Small specimens are not more than 5 mm. in diameter; the largest form examined is 13·5 mm. in height, by 15·5 mm. in thickness, and the wall is 3 mm. thick. Not infrequently the sponges are traversed by smooth curved tubes, sometimes with definite calcareous walls, belonging to some organism which has either bored into the sponge or has been overgrown by it.

There is a well-marked system of excurrent canals which follow the contour of the sponge, and at the surface these are indicated by open, slightly curved furrows, which extend up the sides and over the summit to the cloaca, into which they open. The outer surface of the sponge, as well as the cloaca, is penetrated by numerous oval or rounded canal-apertures about 0·35 mm. in width. As viewed in section the canals are from 0·11 to 0·35 mm. wide.

The skeleton consists of continuous, anastomosing, narrow fibres, from 0·06 to 0·09 mm. in width, disposed so as to form a mesh with small interspaces (Pl. IV, fig. 27). The spicules of the fibres have short rays apparently with truncate ends, which, so far as can be seen, are in close contact and perhaps fused together; but on this point no conclusive evidence can be obtained, for the structure is very indistinctly preserved, and the fibres only show the spicular rays either singly or two or more ranged side by side (Pl. IV, figs. 28 & 29). The rays are about 0·16 mm. in length by 0·04 mm. in thickness. The wall of the cloaca is well-marked and relatively thick; its structure differs from that of the skeletal mesh, but neither the individual spicules nor their mode of union can now be distinguished.

In the regular anastomosis of the skeletal mesh and in the character of the canal-system, these sponges do not differ from normal Pharetrones, and whether they should be placed under this group or with the Lithonina depends on the mode of union of the spicules of the fibres, a feature which is not shown with certainty in any of the specimens that have as yet been examined; but the character of the spicular rays indicates that they may have been firmly cemented together in the same way as in the other sponges from the same horizon described in the foregoing pages. The regular disposition of the mesh, the non-radial arrangement of the fibres or of the spicular rays, and the canal-system, sufficiently differentiate this form from *Plectroninia* and *Bactronella*.

Distribution.—Not uncommon in the Eocene limestone at Flinders (Victoria), associated with *Bactronella australis*, Hinde. Collected by Mr. T. S. Hall, M.A.

EXPLANATION OF PLATES III–V.

Plate III.

Plectroninia Halli, gen. et sp. nov.

Fig. 1. The type-specimen, natural size. From Eocene clays at Griffin's Farm, Moorabool River (Victoria). Collected by Mr. T. S. Hall, M.A.

1 *a*. The same, showing a vertical median section. ×2.

Figs. 2 & 3. Two small specimens, natural size. From Eocene beds at Flinders (Victoria). Collected by Mr. T. S. Hall.

Figs. 4–15. Three-rayed spicules from the dermal layer. Fig. 13 × 1000; the others ×200.

16–22, 24. Various forms of four-rayed spicules from the inner part of the dermal layer. ×200.

25, 26, 28. Minute four-rayed spicules, probably immature forms. From the dermal layer. ×500.

Fig. 27. A four-rayed spicule, with the facial rays incipiently expanded at the ends. ×200.

Figs. 23 & 29. Immature three-rayed spicules from the dermal layer. Fig. 23 × 400, and fig. 29 ×1000.

30–38. Three-rayed 'tuning-fork' spicules of various forms; the shafts and the prongs are in part incomplete. From the inner portion of the dermal layer. ×500.

39 & 39*a*. Very slender subcylindrical spicules, pointed at both ends, either smooth or rough with minute prickles. From the interspaces of the skeletal mesh. ×500.

40 & 41. Straight, styliform spicules, from the interior of the sponge. ×500.

Fig. 42. Straight, pin-shaped spicule. ×500.

Figs. 43 & 44. Two imperfect cylindrical spicules, with styliform or lance-shaped ends; from the outer surface of the dermal layer. ×200.

Fig. 45. Acerate spicule from the inner portion of the dermal layer. ×500.

Figs. 46 & 47. Elongate cylindrical spicules, from the interspaces of the mesh. ×500.

48–82. Different forms of irregularly modified four-rayed spicules from the basal layer and from the floors or platforms traversing the sponge. ×200.

Fig. 83. A small fragment of the basal layer, showing the spicules in position. ×200.

Plate IV.

Plectroninia Halli (continued).

Fig. 1. A fragment of the outer surface of the dermal layer, showing the parallel disposition of the elongated cylindrical spicules. ×200.

2. A fragment of the basal layer. ×200.

3. A vertical section of a portion of the basal layer. ×200.

Figs. 4 & 5. Vertical sections of the skeletal mesh, showing the radial arrangement of the apical rays of the spicules and the mode of junction of the facial rays. ×60.

Fig. 6. A broken-off fragment of the skeleton, showing the spicular structure of the fibres. ×60.

7. An individual four-rayed spicule of the skeleton, showing the expanded terminations of the facial rays and the tapering spined apical ray. ×100.

8. Another skeletal spicule, with one of the facial rays elongated and terminating obtusely. The spicule is invested by the tuberculated calcitic pellicle which covers the mesh-fibres. ×100.

9. A detached four-rayed spicule, in which the ends of the facial rays are greatly expanded. ×100.

10. A transverse section of the skeletal mesh, showing the canals bounded by the spicular fibres. ×60.

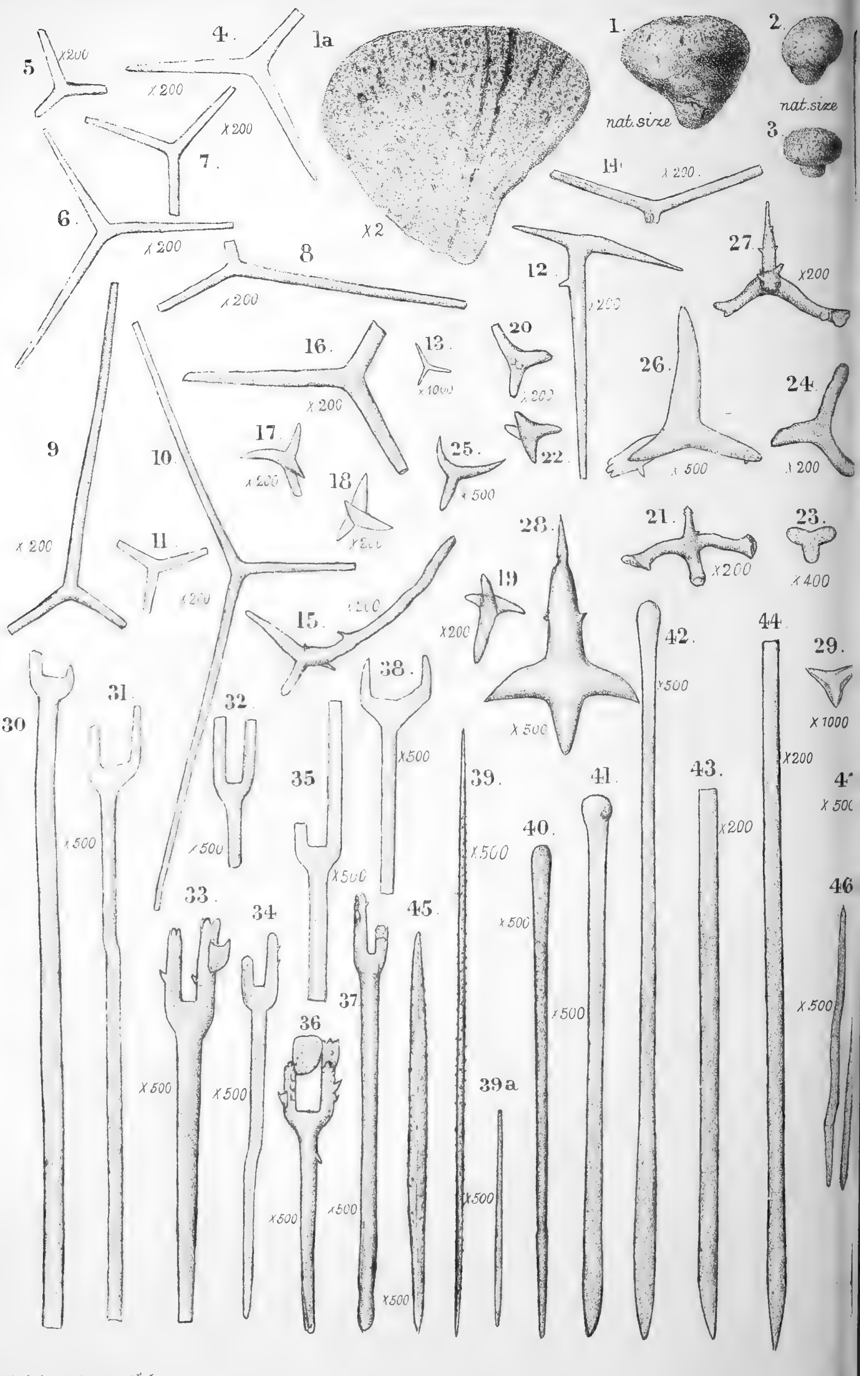
11. A vertical section of the finer skeletal mesh near the base of the sponge. ×60.

Bactronella australis, sp. nov.

Figs. 12–17. Specimens of various forms, showing their mode of growth. Natural size. From Eocene beds at Flinders (Victoria). Collected by Mr. T. S. Hall, M.A.

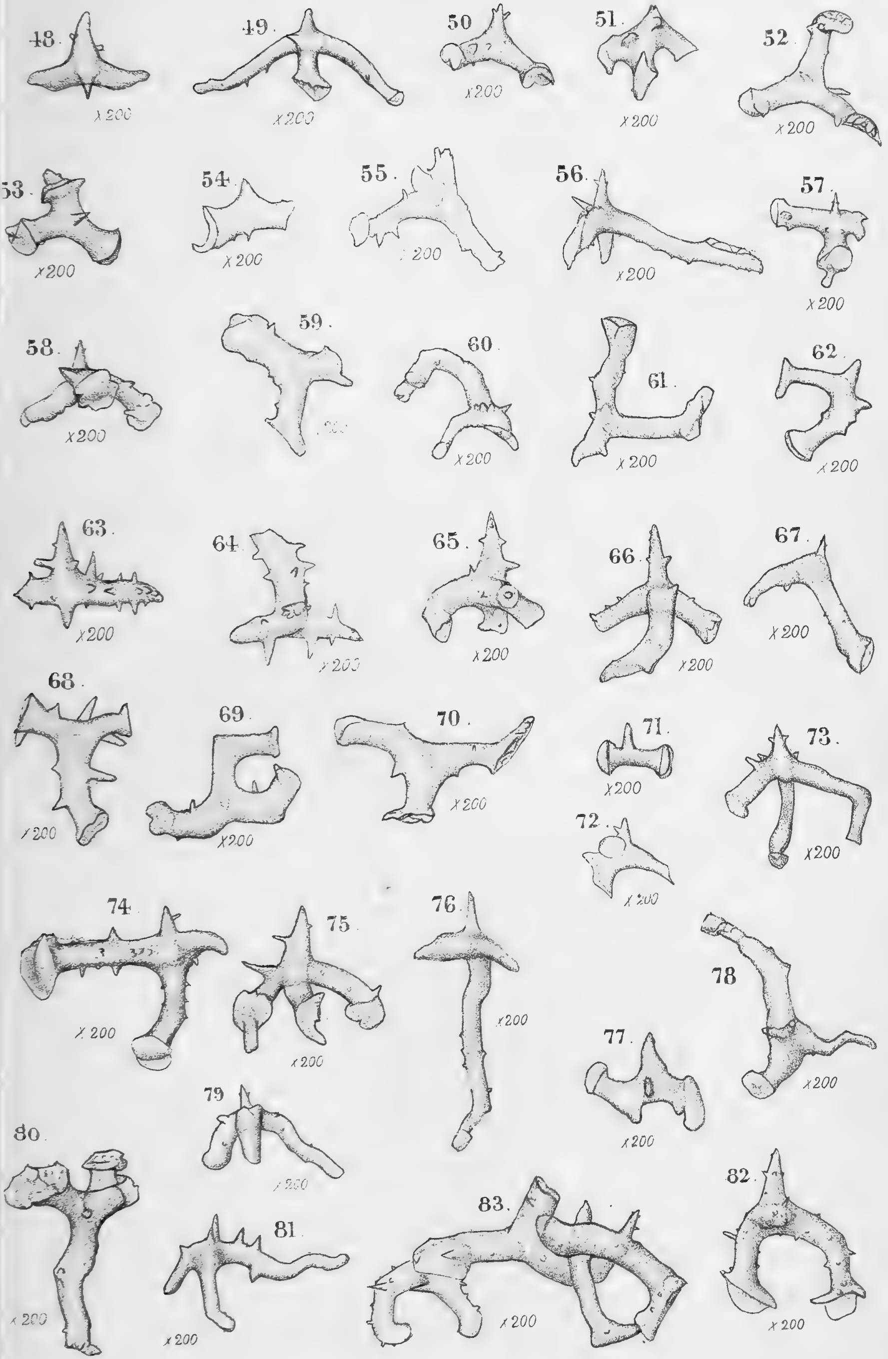
Fig. 18. A portion of the surface, not covered by the dermal layer, showing the disposition of the spicules bounding the radial canals. ×100.

19. Some of the apical spicular rays forming the radial fibres and the irregular spicules connecting them transversely, as seen in a vertical section. ×100.



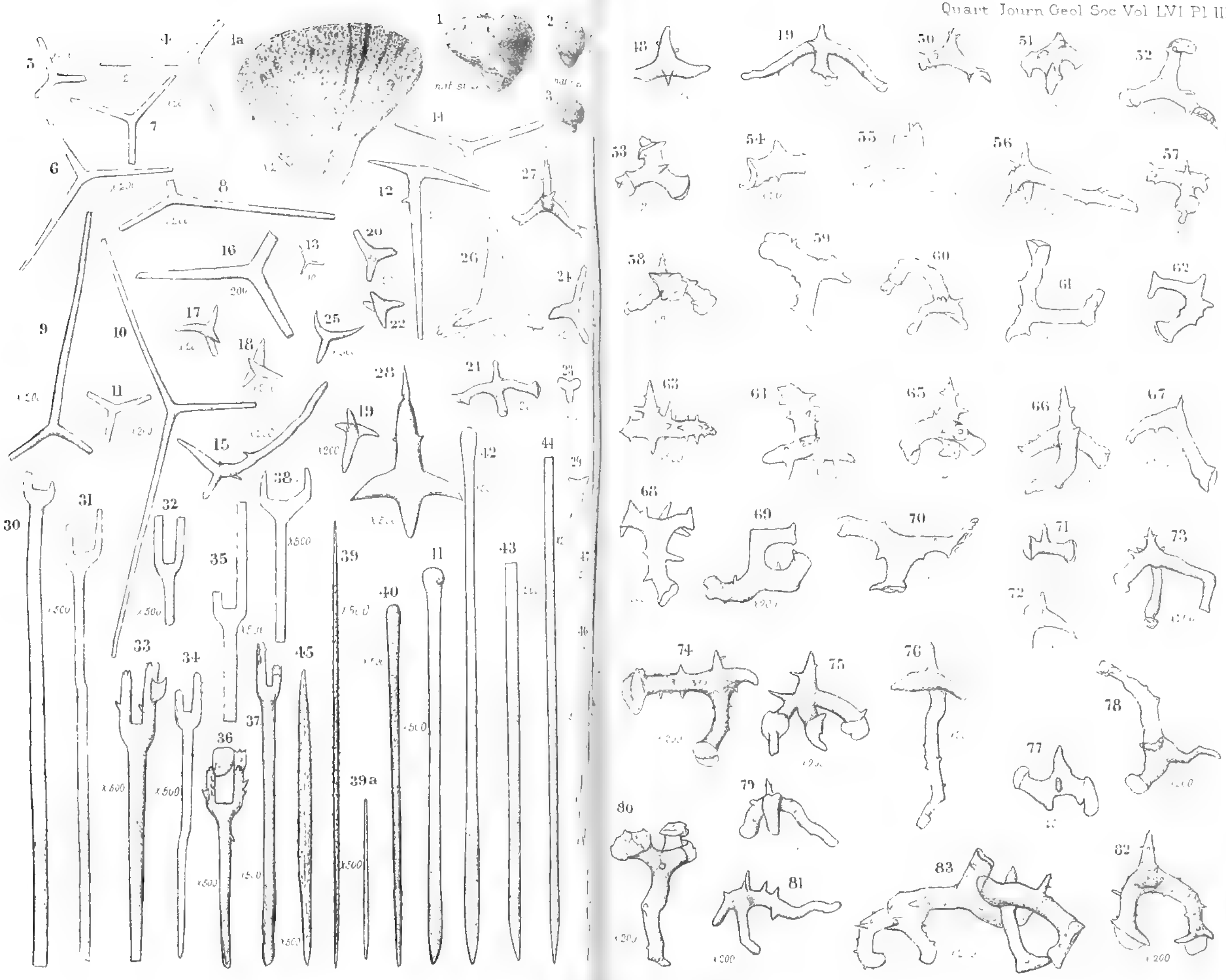
A. T. Hollick del et lith.

CALCISPONGES FROM THE EOCEN



Mintern Bros. imp.

TRATA OF VICTORIA (AUSTRALIA).



A T. Hollick del et lith

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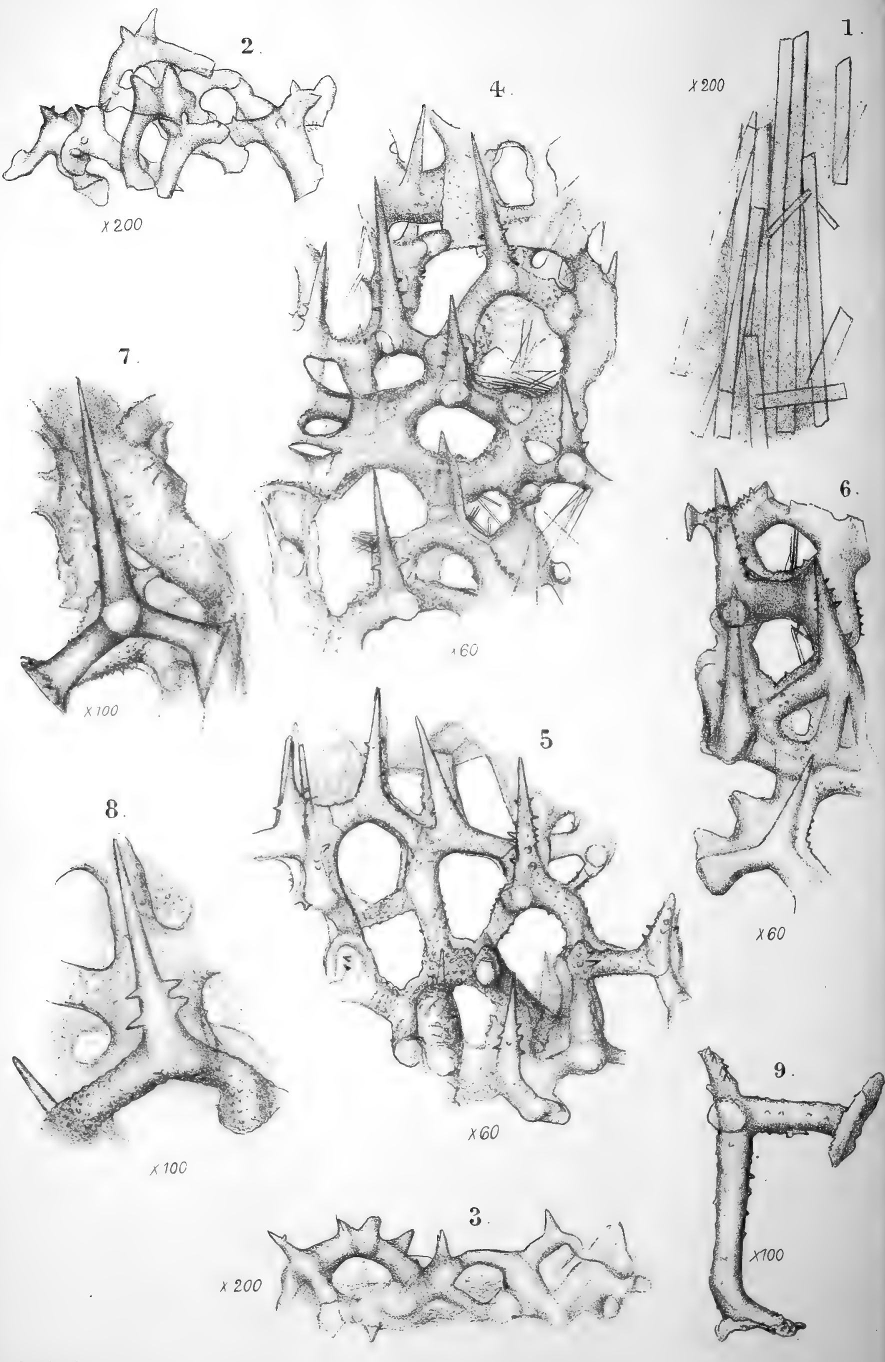
CALCISPONGES FROM THE EOCENE STRATA OF VICTORIA AUSTRALIA.



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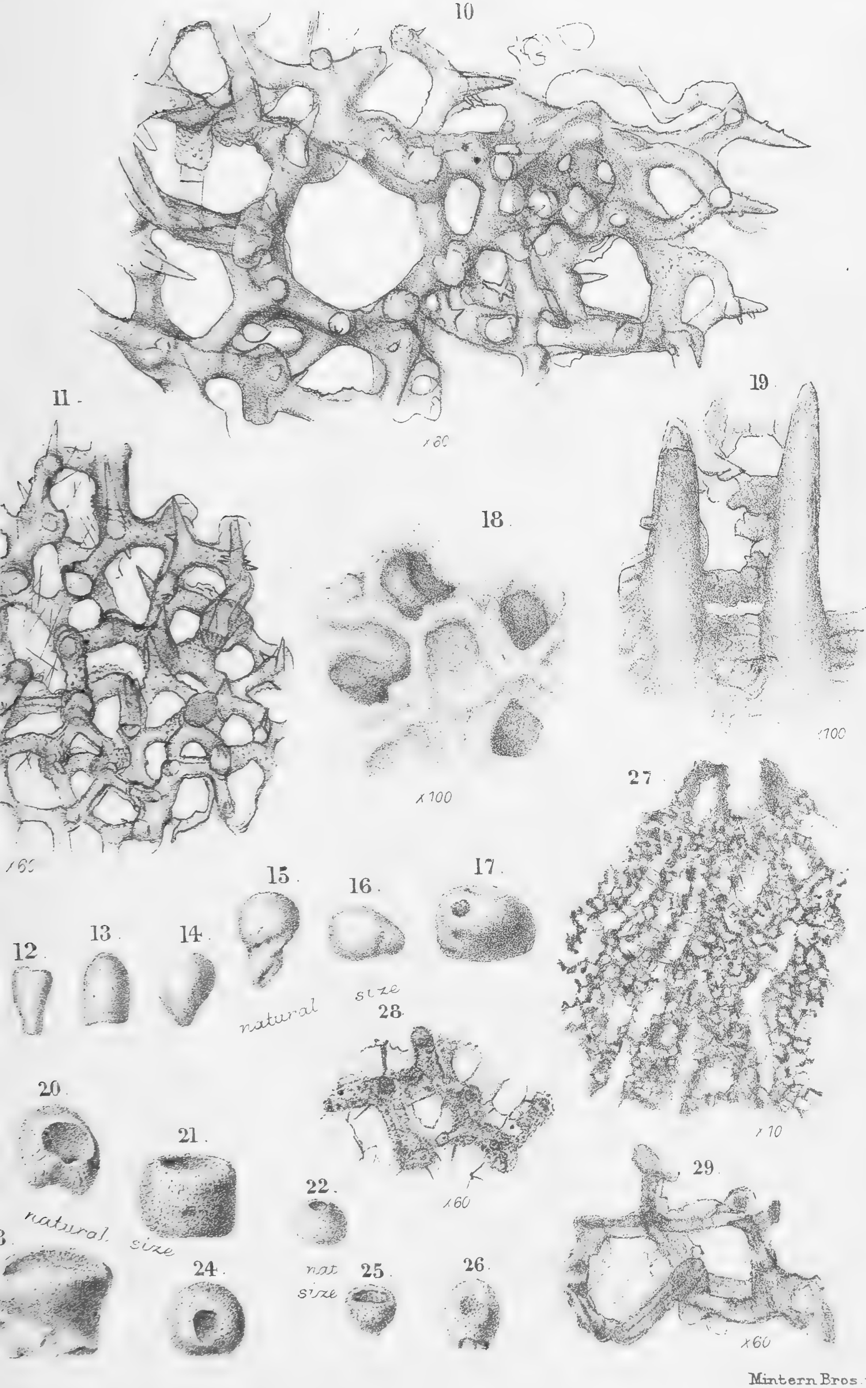
CALCISPONGES FROM THE EOCENE



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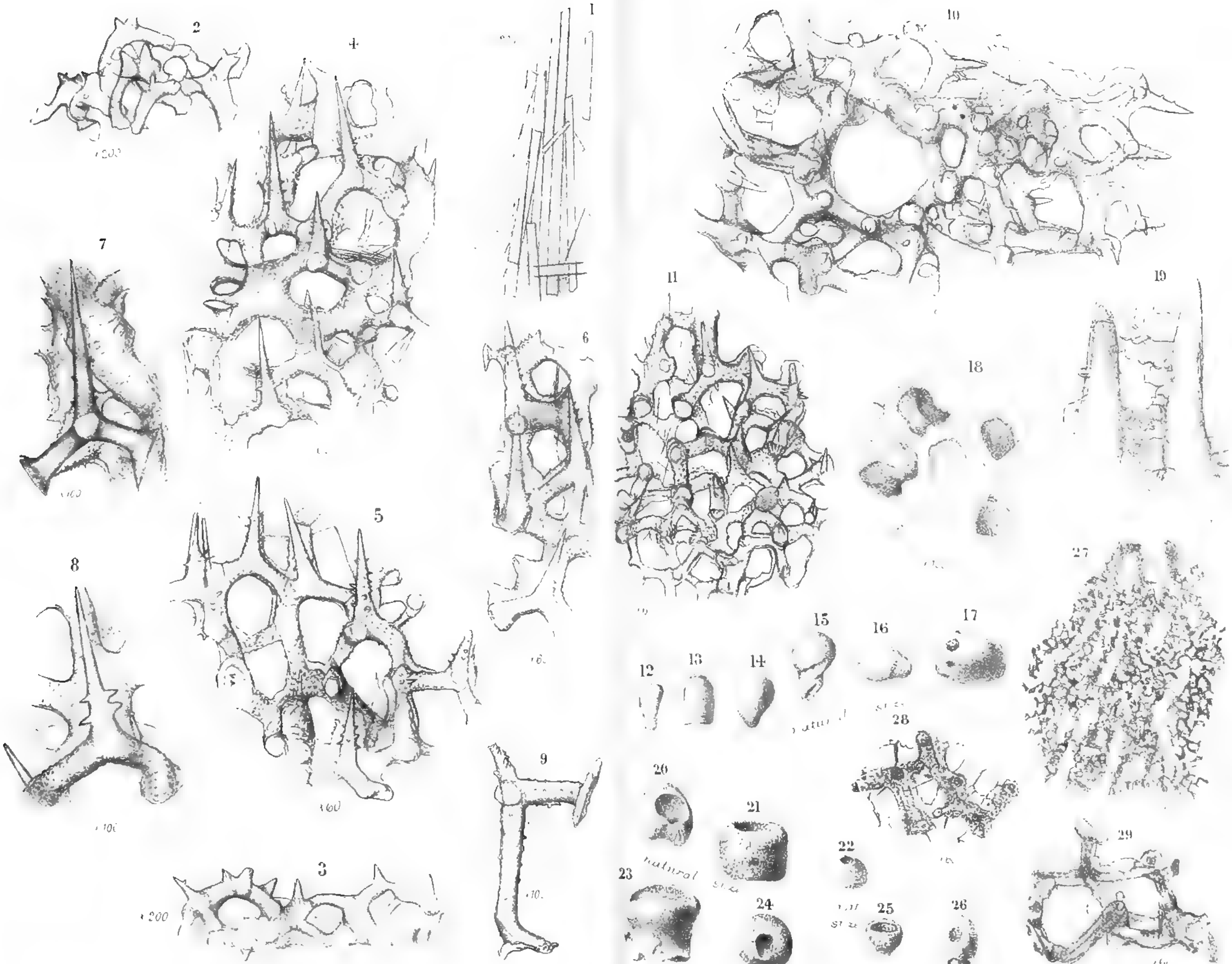
ATA OF VICTORIA (AUSTRALIA).



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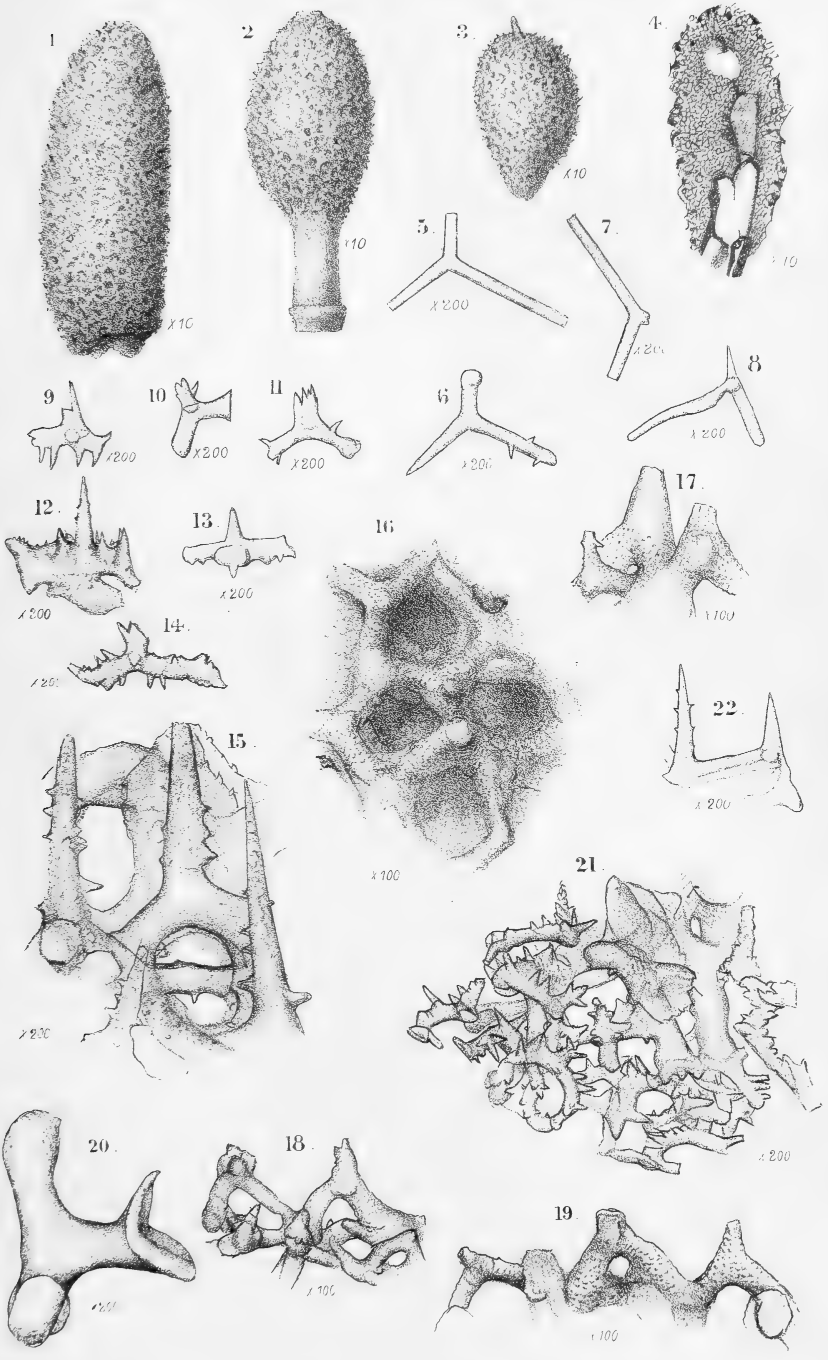
CALCISPONGES FROM THE EOCENE STRATA OF VICTORIA, AUSTRALIA.



A. T. Hollick del. et lith.

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CALCISPONGES FROM THE EOCENE STRATA
OF VICTORIA (AUSTRALIA).

Tretocalia pezica, gen. et sp. nov.

Figs. 20–26. Specimens of various forms, showing their mode of growth. Natural size. From Eocene beds at Flinders (Victoria). Collected by Mr. T. S. Hall.

Fig. 27. A portion of a transverse section, showing the fibres, the direction of the canals, and the thickness of the cloacal wall of the sponge. ×10.

28. Some of the skeletal fibres in vertical section, showing indistinctly the disposition of the spicular rays. ×60.

29. Some of the skeletal fibres as seen in transverse section. ×60.

Plate V.

Bactronella parvula, sp. nov.

Figs. 1–3. Specimens showing the various modes of growth. Fig. 2 is encrusting the upper portion of a sea-urchin spine. ×10. From Eocene beds at Mount Martha, Mornington (Victoria). Discovered by Mr. B. W. Priest.

Fig. 4. A vertical median section of a specimen which has grown over and completely enclosed a fragment of polyzoon. ×10.

Figs. 5–8. Three- and four-rayed spicules from the basal layer. ×200.

9–14. Irregularly modified four-rayed spicules which connect transversely the skeletal-mesh spicules and also form the basal layer of the sponge. ×200.

Fig. 15. A portion of the skeletal mesh, showing the arrangement and mode of junction of the component spicules. ×200.

16. Part of the outer surface of the sponge, showing the spicules bounding the radial canals. ×100.

17. A fragment of the skeletal mesh, near the outer surface of the sponge. ×100.

Figs. 18 & 19. Portions of the mesh next the surface, showing a calcitic tuberculated pellicle. ×100.

Fig. 20. An imperfect skeletal spicule; one of the rays is strongly hollowed out for clasping. ×200.

21. A fragment of the close mesh of the basal layer. ×200.

22. Four-rayed spicules of the basal layer. ×200.

Discussion.

Prof. Sollas expressed his sense of the value of this important paper. The pseudo-Lithistid character of the skeleton of *Petrostroma* was a fact of great interest, which was deepened by the Author's discovery of allied sponges, differing in details but still distinguished by the same character. As regards the chamber-system, it had already been shown that this had passed through similar stages of evolution in the calcareous and siliceous sponges. The Lithonina now proved that a similar homoplasy is presented by the skeleton in the two groups. Two mechanical problems—one the economization of energy in the production of water-currents, and the other the best disposition of rigid material to resist stresses in the organism—had been solved in practically the same manner and independently, by two different groups of organisms. The bearing of this fact on Darwin's theory of evolution was worthy of close consideration. It was reassuring to learn that, notwithstanding the general resemblance of the Lithonine and Lithistid skeletons, there was no insuperable difficulty in distinguishing them by their morphological characters even in the fossil state. A fresh beginning seemed

now to be made in the study of the Pharetrones, and the discoveries of the Author and Mr. Lister would lead to the solution of this heterogeneous group. It was to be hoped that several obscure organisms would find an explanation in the light of our fresh knowledge of the Calcispongia, and the Author's investigations on *Porosphæra* would be eagerly awaited by palæontologists.

The AUTHOR replied that it was satisfactory to know that the importance of these sponges from an evolutionary point of view was recognized by so competent an authority as Prof. Sollas. The complete fusion of the spicules in the fibres was fairly recognizable in the material examined. He thanked the Fellows for their kind reception of the paper.

7. *The* SILURIAN SEQUENCE *of* RHAYADER. By HERBERT LAPWORTH, Esq., Stud.Inst.C.E., F.G.S. (Read November 22nd, 1899.)

[PLATES VI & VII—Vertical Sections & Geological Map.]

CONTENTS.

I. Introduction.

(1) The Ordovician and Silurian Complex of Central Wales.

If an examination be made of any general geological map of Wales, in which the outcrops of the various formations are marked with the colours habitually used by the Geological Survey, the attention is certain to be arrested by the broad spread of pale pink or purple colour which occupies the central portions of the map. It will be seen that this tint spreads over an area representing some 1800 square miles, or nearly one-fourth of the area of the Principality: stretching from Machynlleth to Caermarthen, and from the shores of Cardigan Bay nearly to the town of Builth.

Round this unbroken field of pale tint upon the map sweep more strongly-coloured bands which mark the outcrops of the bordering formations; but within the central field itself little or nothing is given which would enable one to gather an idea of the sequence or distribution of its rocks. Even upon the latest Index Maps of the Geological Survey, we find merely a few scattered reference-letters,—b^2, b^3, b^4, b^5,—which indicate that within this great region rocks are known to occur belonging to the Llandeilo, Caradoc, and Llandovery formations; but no attempt is made to mark out the boundaries of the various groups.

The reasons are not very far to seek: we need only refer to any published description of the rocks themselves. In the words of the late Walter Keeping, 'Central and West Central Wales is made up almost entirely of a great series of imperfect slates and greywackes, . . . pale slates and grits. . . . The rock-beds are astonishingly folded into violent contortions, with frequent inversions, . . . so as often to produce the misleading appearance of a regular and continuous ascending series.'[1]

Indeed a glance at almost any of the Geological Survey maps of the region, upon the scale of 1 inch to the mile, is sufficient to convince a geologist of the great amount of rock-folding that has taken place. Patches of conglomerates and grits are shown dotted in yellow, in long lenticular strips amid a general mass of slates in which the dip and strike remain nearly constant. This is an almost certain indication that we are dealing with a country where the rocks are so folded that the outcrops of the more conspicuous strata do not mark continuous bands, but represent the crests of denuded anticlines, or the laps of sharp inversions, as in the case of the strata of the Southern Uplands of Scotland.

Not only do these strata of Central Wales resemble those of Southern Scotland in their monotony and in their excessive folding, but they are similar in a third respect. They are almost everywhere destitute of organic remains, with the exception of a few graptolites; and even these are difficult of extraction, owing to the prevalent cleavage of the rocks. Further, it must be distinctly borne in mind that it was not until thirty years after the publication

[1] Quart. Journ. Geol. Soc. vol. xxxvii (1881) p. 169.

of the Geological Survey maps of the Mid-Wales district that the value of the graptolite as a geological index was realized.[1]

The monotony of the rocks, their folding and their cleavage, and the rarity of fossils, have all conspired to render this region unattractive to the amateur geologist. Some reconnoitring surveys have been made by three or four investigators, and fossils have been quoted from one or two localities. But, as regards the detailed geological structure of this great region, even at the present day little more is known to the scientific world than at the time when Murchison first attacked the country with the geological hammer.

After his first survey (1839) Murchison placed the rocks of the whole of this area in the Cambrian System.[2] Eight years later (1847) Sedgwick attempted a broad grouping of its strata, and founded his well-known Aberystwyth and Plynlimmon Groups.[3]

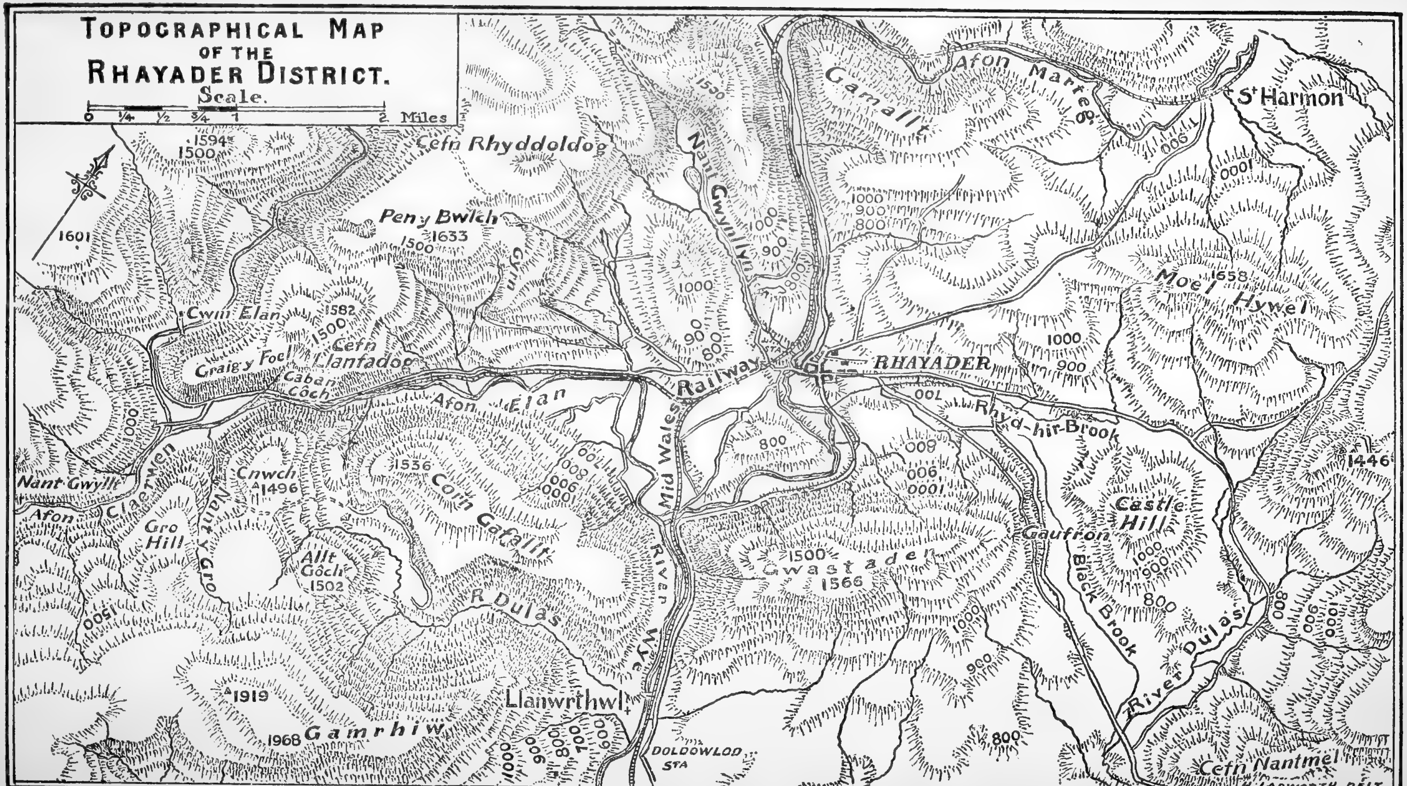
About 1850, the Geological Survey maps of the district were published, prepared from the surveys of Ramsay and Aveline, and the greater part of the region was indicated as Lower Llandovery, on the ground that the Survey officers had actually discovered Lower Llandovery fossils within its limits.[4]

Nothing of apparent importance was brought forward during the succeeding thirty years; but in 1869 Mr. Hopkinson published a list of a few graptolites which he had detected at Aberystwyth.[5] At that time, however, no great significance was attached to his discovery.

The first and, indeed, the last research-work, however, that made any serious attempt to elucidate the structure of the region and to prove the relative antiquity of the members of the complex was that of the late Walter Keeping, who, in 1881,[6] showed that nearly the whole of Central Wales was made up of rocks of Upper Llandovery age, much folded and contorted. He suggested, at the same time, that the Tarannon Shales were likely to be present in certain areas.

During the last three or four years I have had exceptional opportunities for studying the strata of a portion of this great rock-complex of Central Wales. About 4 miles west of the town of Rhayader, the River Claerwen unites with the Elan, and to the gathering-ground or common basin of these two rivers the city of Birmingham has recently resorted (1892) for a new water-supply. The scheme of the engineer, Mr. James Mansergh, V.P.I.C.E., involves the erection of masonry-dams for impounding the waters of these streams. The dams are now in course of construction, and the pipe-line, which crosses the Wye immediately south of Rhayader, is now practically completed for some 12 miles to the eastward. Having been engaged as assistant-

[1] Quart. Journ. Geol. Soc. vol. xxxiv (1878) p. 240.
[2] 'Silurian System' 1839, pp. 316, 317.
[3] Quart. Journ. Geol. Soc. vol. iii (1847) p. 153.
[4] Geol. Surv. Mem. vol. iii (1866) Ramsay's 'Geol. of North Wales' 1st ed. p. 8.
[5] Journ. Quekett Micr. Club, vol. i (1869) p. 116 & pl. viii.
[6] Quart. Journ. Geol. Soc. vol. xxxvii (1881) p. 141.



TOPOGRAPHICAL MAP
OF THE
RHAYADER DISTRICT.
Scale.
0 1/4 1/2 3/4 1 2 Miles
Cefn Rhyddoldog
Peny Bwlch
1633
1500
1594
1601
Cwm Elan
1582
Cefn Llanfadog
Craig y Foel
Caban Côch
Afon Elan
Nant Gwynllyn
1530
Gamallt
Afon Marteg
St Harmon
Moel Hywel
1658
RHAYADER
Railway
Mid Wales
River Wye
Rhyd-hir-Brook
Gaufron
Castle Hill
Black Brook
River Dulas
1446
Gwastaden
1566
1536
Corn Gafallt
R Dulas
Cnwch
1496
Nant Gwyllt
Afon Claerwen
Gro Hill
Nant y Gro
Allt Gôch
1502
1919
1968
Gamrhiw
Llanwrthwl
DOLDOWLOD STA
Cefn Nantmel
H. LAPWORTH. DELT.

engineer on the building of this portion of the aqueduct, I have devoted my occasional leisure-hours to a study of the geology of the immediate neighbourhood, and the present paper embodies the results of my researches. The area examined lies more or less symmetrically about the town of Rhayader, and therefore may be fittingly termed the Rhayader District.

(2) The Rhayader District.

(See the topographical map on p. 70.)

(*a*) General Characteristics.

The town of Rhayader is situated near the eastern fringe of the Central Wales complex, where the waters of the Wye enter a somewhat lozenge-shaped valley, stretching from north-east to south-west. From end to end this valley has a length of some 7 miles, and a breadth of a little over 1 mile at its widest. The Wye may be said to divide it into a western area drained by the Elan, and an eastern drained by the Rhyd-hîr Brook: these two streams empty themselves into the Wye. The little market-town of Rhayader lies to the north of their confluences, nestling against the northern border of the valley itself.

The Rhayader Valley is bordered on the south by the long ridge of Gwastaden. This rises to a height of some 900 feet above the bed of the Wye, and shuts off like a great wall the country lying to the south. The border of the Rhayader Valley crosses the Wye a little below its junction with the Elan, and, passing westward along the ridge of Corn Gafallt Hill, swings round in a gentle curve, which terminates west of the Elan Village. At this point the hilly border is cut through by the deep gorge of Caban Côch, overhung by steep crags, and forming the exit from the Vale of Nantgwyllt. On the south side of Corn Gafallt the hill drops suddenly into the desolate valley of the Dulas, part of which, at least, must be included in the Rhayader District. On the north-east, beyond Castle Hill, the Rhayader Valley may be considered to end between the hills of Moel Hywel and Llan Gôch. On the north and north-west, between Moel Hywel and Caban Côch, the Rhayader Valley is shut in by the vast plateau of Central Wales, which extends in countless undulations westward for over 30 miles, to the coast-line of Cardigan Bay.

The district lying south and east of the Rhayader Valley is in striking contrast with that lying north and west. From the hill of Gwastaden southward to Builth run a regular series of alternating ridges and hollows parallel to the border-lines of the surrounding formations. Indeed, the Gwastaden range, and even the Rhayader Valley, may be said to form part of this alternating series.

The physical characters of the districts lying outside the Rhayader Valley, particularly on the north and west, are those of bleak moorands ribbed by ridges of cleaved slate. As a consequence, the

country is devoid of agricultural value, except in the low-lying areas; but is utilized as an immense expanse of sheep-runs, some of which are many thousands of acres in extent. Inside the valley, however, in the immediate neighbourhood of Rhayader, the greater part of the land is cultivated; but the soil is poor, and does not seem well able to support the growth of corn.

The rocks of the Rhayader District may be described briefly as consisting of conglomerates, grits, shales, slates, and mudstones. The ridges and caps of the hills of Gwastaden, Corn Gafallt, Cnwch, and Allt Gôch are formed chiefly of grits and conglomerates. These graduate first into flagstones, and eventually into shales and mudstones. Through these softer rocks the rivers have cut their way, carving out the valleys and low-lying areas. The Rhayader Valley proper is floored mainly by shales and mudstones; and from a point as far as 6 miles north of Rhayader to the base of Gwastaden the Wye may be followed without once crossing a bed that may be strictly termed arenaceous. One or two very thin limestones occur among the shales in the river-course south of Rhayader, but they appear to be of merely local occurrence, and with these exceptions limestones may be said to be absent from the district.

The strike of the rocks is roughly north-east and south-west. The dip of the strata varies: the average inclination of the beds, however, may be taken as from 20° to 30° north-westward. The argillaceous rocks are all highly cleaved: even those that occur between thick bands of grit and conglomerate have suffered. Indeed, so intense has been the cleavage in certain areas that it affects many of the thickly-bedded arenaceous rocks. The strike of the cleavage is parallel to the strike of the bedding.

Through the central portion of the Rhayader District the beds run fairly evenly along their lines of strike, but as we approach the western limits folding commences. At Caban Côch, crumplings and bucklings in the Caban Conglomerates on both sides of the gorge can be well seen from the high road.

A fault of some considerable downthrow occurs in the neighbourhood of Caban Côch, accompanied by others of less importance. This main fault was detected by the officers of the Geological Survey about the year 1850, and is shown upon the Horizontal Sections. It is usually referred to as the Abernant Fault by the engineers on the Elan Valley Works, and to this term I propose to adhere. A long strike-fault runs along the Rhayader Valley from north-east to south-west, with several branching dip-faults. These, however, will be mentioned on a subsequent page, when the detailed structure of the various rock-groups is dealt with.

(*b*) Historical Summary.

The earliest reference to the Rhayader District is found in Murchison's 'Silurian System,'[1] in which a short description is

[1] London, 1839, pp. 316, 317.

given of the rocks of Gwastaden and Craig-y-foel. These rocks are assumed to be the same, and are assigned to the Upper Cambrian horizon. A geological section of the country is also given in the accompanying plates.

In 1847 Sedgwick, in his paper on the 'Classification of the Fossiliferous Slates of North Wales, etc.,'[1] described the slates of this district and introduced the term Rhayader Pale Slates. At the same time, however, he clung to Murchison's opinion that they belong to the Cambrian System, and placed them above his Plynlimmon and Aberystwyth Groups.

About this time the officers of the Geological Survey were engaged on an examination of the rocks of the district. In 1850, Sheet 56 N.W. of the Survey maps, which includes the town of Rhayader, was published. This map embodies the work of Ramsay and Aveline; and for the first time boundary-lines are shown separating arenaceous from argillaceous rocks. In company with the maps, Sheet 5 of the Horizontal Sections was issued. This includes a section through the Caban Côch area, which brings out clearly the arrangements of the various grits and conglomerates in that locality. In this section, however, as in the map, the various beds were considered as belonging to one and the same formation. But a striking change of opinion had been brought about within the previous three years: for, instead of being assigned to the Cambrian, the rocks were referred to the Lower Llandovery, on the grounds already stated (p. 69).

About twenty years later (in 1872), the Rev. W. S. Symonds published his well-known 'Records of the Rocks.' On pp. 135–36 of that volume will be found a short description of the rocks and scenery of the district. Comment is made on the difficulty of working out the geology, and it is stated that up to that time the stratigraphy was by no means cleared up. The Gwastaden and Caban rocks are briefly described, and are both assigned to the Lower Llandovery.

In 1881 the late Walter Keeping, in his most valuable paper on the 'Geology of Central Wales,'[2] advanced a new suggestion as to the arrangement of the various rock-groups between Aberystwyth and Rhayader. He showed that the Plynlimmon Grits overlie the Aberystwyth Group, and he proved the latter to be of Upper Llandovery age. In the Plynlimmon Grits he found no fossils; but because of their superior position he assigned them to the Tarannon horizon. At the same time he united in one single group the Gwastaden Grits, the Caban Côch Conglomerates, and the Rhayader Pale Slates; and he suggested that it occupied the same stratigraphical parallel as the Plynlimmon Grits.[3]

It has been pleasant to find, from the results of my own researches, that many of the suggestions of the later investigators were, in part, correct. In the present paper I shall endeavour to show that, within

[1] Quart. Journ. Geol. Soc. vol. iii (1847) p. 153.
[2] *Ibid.* vol. xxxvii (1881) p. 141.
[3] *Ibid.* p. 161.

the limits of the Rhayader District occur representatives of the Lower Llandovery, Upper Llandovery, and Tarannon formations, capable of being divided into petrological and palæontological zones. The sequence of these zones is demonstrable by stratigraphical evidence, and they may be correlated, by means of fossils, with their equivalents elsewhere.

II. Stratigraphical Relations of the Rocks of the Rhayader District.

(A) The Gwastaden Group.

In describing the rock-sequence of an area it is advisable to establish some typical section to which the reader may turn at any time. In the present case, the rocks flanking the northern side of Gwastaden and forming the floor of the Rhayader Valley are best exposed, curiously enough, along a line that a geologist would naturally select, on first attempting to unravel the sequence. This line may be fixed as running from the summit of Gwastaden to the town of Rhayader itself. Taking its starting-point at about $\frac{1}{2}$ mile north-east of the cairn and following a small stream at the eastern end of Gigrin Prysg, which may, for the sake of convenience, be termed the Prysg stream, it reaches the Wye at about $\frac{1}{4}$ mile south of the workhouse. From this point the section follows the river upstream for about $\frac{1}{2}$ mile, and terminates in the centre of the town itself. The rocks occupying the greater part of this section form a continuous ascending series, which I have named after Gwastaden Hill (pron. 'Gwastedden'), along whose slopes their characters may best be studied. By a curious coincidence this Gwastaden Group is not only shown to its greatest advantage along this line of section, but the order of the beds is practically undisturbed by folding or faulting. Moreover, as will be shown subsequently, the Gwastaden Group here attains its maximum development.

(a) *Description of the Sections in the Rhayader Valley.*

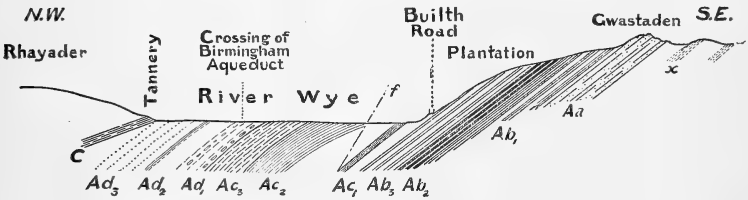
(1) Typical Section through Gigrin Prysg and the Wye.

The ridge of Gwastaden is formed by a series of thickly-bedded grits, which run along the hill from end to end. This ridge is the most prominent feature of the hill itself, and the grit-beds are well exposed in one continuous line for a length exceeding 2 miles along the line of strike. We have thus a convenient datum or base-line for the succeeding three or four sections. At the south-western end of the hill, where these beds sweep down into the Wye, they form a long precipitous crag or cliff over 200 feet high, known as Cerig Gwynion, and it is here perhaps that the finest exposure of these grits is exhibited. The name Cerig Gwynion Grits, then, naturally suggests itself as the most suitable term for this group.

(*a*) Cerig Gwynion Grits (Aa).

These grits are not exposed in the stream of our typical section, but make their appearance about 100 yards to the east; and still farther east, where a small footpath crosses the outcrop, a vertical thickness of about 100 feet is laid bare (see fig. 1). The beds run

Fig. 1.—*Section from Gwastaden to Rhayader.*



[Approximate length = $1\frac{1}{4}$ miles.]

C = Rhayader Pale Shales.
A = Gwastaden Group.
Ad = Gigrin Mudstones.
Ad_3 = Pale Grey Mudstones.
Ad_2 = Zone of *M. convolutus*.
Ad_1 = Calcareous-Nodule Beds.
Ac = Ddôl Shales.
Ac_3 = Zone of *M. fimbriatus*.
Ac_2 = Zone of *M. cyphus*.
Ac_1 = Zone of *M. tenuis*.
Ab = Dyffryn Flags.
Ab_3 = *D. modestus* Flags.
Ab_2 = Rottenstone Beds.
Ab_1 = Micaceous Flags and Grits.
Aa = Cerig Gwynion Grits.
x = Blue-black Shales.
f = Fault.

up to about 6 or 8 feet in thickness, and dip at an angle of about 28° north-westward. The rock itself is a very hard, compact, greenish-grey siliceous grit or grauwacke. It is extremely tough under the hammer, and, being almost free from calcareous or felspathic matter, fragments are detached from its weathered surfaces with as great difficulty as from beds newly laid open in the quarry. A detailed description of this rock, however, will be given on a subsequent page (p. 95). The total calculated thickness of the group at this point is about 170 feet.

About 50 yards south of this grit-band, a small outcrop of an underlying group of a very different mineralogical character may be seen. There is no trace of the siliceous matter of the grits, but only the argillaceous material of a set of flaky, blue-black shales. These shales are very highly cleaved, and, indeed, may be described as schistose. They create at once the impression that they are of far greater geological antiquity than the beds of the overlying grit-group. Isolated rock-patches, extending for several hundred yards southward, still reveal the same general characters. The actual line of junction of the shales and the grits is not exposed, but no transitional phases seem to exist between the rocks of the two groups. It would appear in fact, from the very sudden petro-

logical change along our datum-line, that a complete alteration took place in the physical condition of the sea-floor between the periods of deposition of the two series.

(*b*) Dyffryn Flags.

Micaceous Flags and Grits (Ab_1).—Resuming our section above the grit-band, we follow the Prysg stream as it descends the long dip-slope of the top of the thickly-bedded grit-group. For about 100 yards or so no rock is visible: at the first bend of the stream to the left, however, a thickness of about 30 or 40 feet of the succeeding group is displayed. Grits are still present; commencing at only 2 feet in thickness, they thin out to about 3 inches at the end of the exposure. Intercalated with these, and forming the predominating feature of the group, is a series of thin, platy, gritty flags, and micaceous blue slates, ringing under the hammer, and weathering to a dark bronze tint. This bronze hue often shows an iridescence, which gives to this portion of the group a characteristic appearance. A few specimens of *Climacograptus normalis*, Lapw. have been extracted from the flags.

A hundred yards south of the fence over the stream, the grits are represented by a few $\frac{1}{2}$-inch grit-bands only. The greater part of the series consists of hard, micaceous, dark-blue flags and slates. These are often interbanded with thin grits, occasionally showing very fine, close, carbonaceous laminæ, and, more rarely, ferro-manganese sandy partings. The most marked feature, however, is the strongly pronounced dark reddish-brown weathering of the exposed surfaces.

Immediately north of the fence mentioned above, after passing over a few feet of the last subdivision, a decided change in some of the lithological characters is noticeable. The brown tint due to weathering in the lower series has given place to a brilliant red-orange or hæmatitic colour. The grits are now thicker, averaging 3 or 4 inches, but are somewhat sandy in composition. They are dark grey, and generally banded with carbonaceous seams. Other peculiarities of this subdivision are the occurrence of very thin plates of grit, intercalated among the flags, and the occasional presence of patches of white calcite in thin films, showing in certain lights a beautiful pearly lustre. The flags again are much softer, and are closely banded with fine black laminæ. From these flags, at a distance of a few yards above the foot of the first cliff below the fence, I have obtained *Diplograptus acuminatus*, Nich., *Climacograptus parvulus* sp. nov., *Cl. normalis*, and *Dictyonema* sp. Beyond doubt the most striking characteristic of this subdivision is the pronounced red coloration due to weathering. The colouring-matter is often present in such large quantities as to stain the fingers.

The total thickness of these micaceous flags and grits, from the top of the Cerig Gwynion Grits to the end of the last subdivision, may be estimated at 180 feet.

Rottenstone Beds (Ab_2).—Continuing the section up to and beyond the second cliff below the fence previously mentioned, one next passes over a thickness of 50 feet of rock (Ab_2), possessing features so distinctive that it is clearly entitled to rank as a separate division. The brilliant weathering colour of the underlying beds extends for a short distance into this group, but through the greater part of it tones down into a pale red-orange. The black-banded grits are still met with in this group, but are rarely more than ½ inch thick. The blue flags become thicker as the grit-bands thin out, and at the summit of the division are as much as 2 feet in thickness. They are, however, less micaceous than in the underlying rock-group. At the commencement of this group intercalated shales make an appearance for the first time. These are distinctly platy in the lower half, but as they pass up they become softer, and finally are seen to be almost shivery. Readily yielding to the influence of the weather, and splitting off in numerous fragments, they strew the banks of the stream with a litter of shaly screes. At the summit of the group these shales are highly nodular in structure, and in this form pass into the lower subdivision of the succeeding group.

The chief characteristic of this division is the presence of a large quantity of calcareous matter in the beds. This is especially evident in the occurrence of bands of rottenstone among the flags and shales. These rottenstone-seams reach a thickness of 3 or 4 inches. The calcareous matter has often been almost removed, and has left only a very soft earthy deposit of iron-oxide. The rottenstone-bands thin out and disappear at the top and bottom of the group, but in its centre they form so distinctive a feature that wherever this division is exposed it is recognizable at a glance, and has, in consequence, constituted a zone of the greatest utility in unravelling the rock-sequence of the district. The dip is about 33° north-westward.

Fossils are very rare in this zone, but a few of the carbonaceous bands yield *Diplograptus modestus*, Lapw. and *Climacograptus normalis*.

Diplograptus-modestus Flags (Ab_3).—The Rottenstone Group passes upward into a series of hard grey-and-blue flags with flaggy shales (Ab_3). Some of the blue flags of the previous group have here given place to grey flags, and the grits are represented by only a few ½-inch bands, dying out at the summit of this division into thin white siliceous seams, scarcely exceeding $\frac{1}{16}$ inch in thickness. The flags average 9 inches at the base of the division; but at the top they are only about 6 inches thick; in the upper half they are usually interbanded with fine brown and green seams. They weather to a pale orange or yellow colour. The dip of the strata slightly increases as we ascend in the group, and at the point where the Prysg stream crosses the Builth road, practically at the summit of this division, the rocks dip at an angle of 35°. The total thickness of the group is about 300 feet. Characteristic

fossils are to be obtained from a few black bands about 10 yards below a small footpath over the stream, about 130 yards above the road. From these beds at this point I have extracted *Diplograptus modestus*, *D. longissimus*, Kürck., *Climacograptus rectangularis*, M'Coy, and *Cl. medius (?)* Törnq. In a thin nodular band at the top of the plantation occur, in addition to *Climacograptus rectangularis*, examples of the genus *Lindstrœmia*, and badly preserved specimens of *Orthis* sp.

The rocks of the foregoing series, including the Micaceous Flags and Grits (Ab_1), the Rottenstone Beds (Ab_2), and the *Diplograptus-modestus* Flags (Ab_3), have a common lithological character, which distinguishes them collectively from the strata above and below, namely, the preponderance of flags. They form together a very natural group, which I have named the Dyffryn Flags, after a small cottage called The Dyffryn (pron. 'Duffrin') on the Builth road, about $1\frac{1}{2}$ miles from Rhayader. This lies full in the centre of the outcrop of the group.

The group has been described at some length in the preceding paragraphs, in order to show that within its main divisions, on the line of the typical section, certain subdivisions also can be made out. These subdivisions have been used in mapping as far as they were applicable, but as the examination of the rocks was gradually extended farther east or west of the typical section it was found that these minor subdivisions could not be readily made out. The three divisions of the Dyffryn Flags, however, enumerated above, maintain their general lithological characters more or less throughout the district, and at the same time are quite sufficient to prove the general sequence.

(*c*) Ddôl Shales.

Zone of *Monograptus tenuis* (Ac_1).—Crossing the Builth road and ascending to the Wye our section-line meets the river at the bend. Lining the river-banks on the south side of a small island in the crook there is an exposure of rocks strikingly dissimilar to any with which we have hitherto met. In place of the pale weathered grey flags and flaggy shales of the preceding group a series of blue-banded, blue-hearted shales with a few thin flags come in here. The shales weather to brilliant red-brown and mottled green, and are characterized by their curious hummocky or mammillated surfaces. The dip at this point is about 35° north-westward.

No further exposures of the rocks of this division occur in the river-course; but on the east side of the Builth road, about 50 yards north of a small stream which crosses the road, a few patches of these shales have been laid open. They exhibit the same general peculiarities of weathering coloration, but here a brilliant scarlet predominates. The shales are more shivery, and show a curious ashy whiteness on their weathered surfaces. The flags are sandy and dark grey, and the hummocky surfaces form a characteristic feature.

The chief fossil of this group is *Monograptus tenuis*, Portl. which has been met with in one band only, but in great abundance. Its associates are *Climacograptus normalis* and *Cl. rectangularis.* Other exposures of the shales of this group are to be seen up the little brook previously mentioned, and also in the sides of the lane that runs from Cae-newydd to the Rhayader Workhouse. The thickness of this division may be estimated at 250 feet.

Zone of *Monograptus cyphus* (Ac_2).—Succeeding the space allotted to the foregoing division on the line of the typical section, from about 100 yards south to about 50 yards north of Ddôl Farm, is an almost continuous section of bright orange-weathered, thickly-bedded, calcareous, hard, grey sandy flags and grey shales, with thin, ferruginous, sandy bands. From the southern extremity of this exposure to the southern end of Ddôl Farm the individual flags reach a thickness of about 6 inches, and are intercalated with dark-grey and light-blue flaggy shales. They are distinctly nodular in structure, often micaceous in composition, and, like the shales, are peculiarly striped at frequent intervals with ferruginous sandy and green gritty bands. All the beds are more or less calcareous. In places the shales have become thoroughly rotted and disintegrated by the weather, but a compact band of limestone, 2 feet thick, is to be seen in the river-bed in line with the hedge at the south side of Ddôl Farm. It is accompanied by large concretions of carbonate of lime embedded within the shales.

A strike-fault at the southern end of the exposure cuts out a portion of this group, but the total thickness cannot be less than 200 feet. The dip is less than that of the underlying beds, varying from 15° to 20° north-westward.

Passing up towards the top of this zone occasional carbonaceous bands are seen to occur in the flags. From a few bands in the shales near the summit of the group I have extracted *Monograptus cyphus*, Lapw., *Climacograptus normalis*, and *Cl. rectangularis.* By far the commonest fossil is the last-named, which is found throughout the division; but as *Monograptus cyphus* is exclusively confined to it, it is preferable to name the zone after this fossil, especially as *Cl. rectangularis* has a considerable range both above and below.

Zone of *Monograptus fimbriatus* (Ac_3).—A set of limestones, 3 or 4 inches thick, may be taken as the basement-band of this zone. A few beds with limestone-concretions overlie this band, and are succeeded by a series of soft, blue-banded, blue-hearted shales, with occasional grey flags. The grey beds of the underlying group are here entirely supplanted by a series of more or less carbonaceous blue shales, yielding so rich a graptolitic fauna that this zone is marked out as one of especial palæontological interest. These graptolite-shales are generally shivery, and a persistent cleavage cuts everywhere through their bedding-planes at a very acute angle; the shales consequently take the form of thin sheets with sharp, knife-like edges. The graptolites—which are usually

in a state of excellent preservation—skim, so to speak, along the surface for a short distance, then dive under; and, if the slab be sufficiently thin, reappear on the opposite face. Flaggy blue shales are exposed in the group here and there, and it is in these that the investigator should search for fossils. The cleavage has not been of sufficient intensity to penetrate these harder beds. The group is somewhat ferruginous, as may be gathered from the occurrence of thin seams of iron-pyrites, which takes the form of small globules. The flags are generally pale grey or full grey, but in the centre of the group they are of a dark bluish-black. In the lower beds of the zone the chief fossils are *Monograptus communis*, Lapw., *M. fimbriatus*, Lapw., and *Petalograptus palmeus* var. *latus*, Barr.

Overlying these comes a thickness of about 20 feet of shales with *Monograptus triangulatus*, Hark. and *Diplograptus sinuatus*, Nich., in addition to the foregoing species. *Monograptus triangulatus* is exclusively confined to this band. The last 60 feet of the zone yields:—

Monograptus communis.	*Diplograptus tamariscus*, Nich.
—— *fimbriatus.*	—— *magnus* sp. nov.
—— *attenuatus*, Hopk.	*Petalograptus palmeus* var. *latus.*
—— *leptotheca*, Lapw.	—— *minor*, Elles.
—— *gregarius*, Lapw.	*Climacograptus undulatus*, Kürck.
—— *argutus*, Lapw.	—— *normalis.*
—— *crenularis*, Lapw.	—— *rectangularis.*
Diplograptus sinuatus.	*Orthoceras* sp.

Diplograptus magnus is limited to the topmost 25 feet, and makes its first appearance in company with *Climacograptus undulatus*. *Monograptus leptotheca* also is first found in these topmost beds.

The total thickness of this zone is about 150 feet.

The whole of the foregoing division—the Ddôl Shales,—including the zones of *Monograptus tenuis* (Ac_1), *Monograptus cyphus* (Ac_2), and *Monograptus fimbriatus* (Ac_3), is named after Ddôl Farm (pron. 'Thole,' like 'those'), which is built on the central beds of the division.

(*d*) Gigrin Mudstones.

Calcareous-Nodule Beds (*Ad_1*).—A short distance below the masonry-outlet to the Wye overflow-pipe on the Birmingham aqueduct the fourth and highest division of the Gwastaden Group begins.

The change between this division and the underlying one is remarkable for its suddenness. So great is it that a knife-blade can be inserted into the plane at which one group ends and the other begins. This would lead the observer to suppose that a fault existed at this point. Indeed that may be the case, but such a fault can have no great throw, as detailed mapping has shown no alteration in the thickness of either of the groups to the eastward or westward.

The Gigrin Mudstones fall into three distinct lithological divisions. The lowest of these may be summarized as a series of

nodular bluish-grey and greenish-grey mudstones and flags, characterized by the occurrence of nodules of carbonate of lime. All soft shales have disappeared.

The calcareous nodules reach a maximum diameter of about 12 inches in the basement-beds, but throughout the remainder of the division they average only from 3 to 4 inches in diameter. As a rule the carbonate of lime has been dissolved, leaving a small nodule or ball of dark brown or black, powdery, ferro-manganese oxide. In the river-bed itself the nodules have been washed away by the river-waters, but a few may be seen standing out above the average river-level in marked contrast against the pale grey mudstones. Another peculiarity of the group is the presence of curious blue and black lenticular markings on the fractured surface of the mudstones and flags. These occur in nearly all the beds of the river-exposure, up to the point where the Birmingham Aqueduct crosses the Wye. As we approach this crossing the flags become somewhat sandy, and assume a curious speckled appearance. Thin hard blue bands are not uncommon in the group. Fossils are rare; but immediately above the overflow-outlet occur *Diplograptus magnus*, *Climacograptus rectangularis*, *Cl. undulatus*, and *Orthoceras* sp.

A very rich graptolitic fauna was detected in a few black flags, which were exposed in the river-trench for the Birmingham water-pipes. These black beds cannot be seen in the river-course itself, being covered up by alluvium. The graptolites extracted were in exquisite preservation, and consisted of the following species:—

Monograptus attenuatus.	*Monograptus crenularis.*
—— *leptotheca.*	*Rastrites peregrinus*, Barr.
—— *gregarius.*	*Petalograptus palmeus*, Barr.
—— *lobiferus*, M'Coy.	*Diplograptus tamariscus (?).*
—— *Nicoli*, Harkn.	*Climacograptus undulatus.*

Monograptus leptotheca is by far the commonest fossil in this band; the examples collected are perhaps the best preserved fossils in the district.

The exposure extends for a short distance above the Aqueduct-crossing, and brings the total thickness of the group to at least 140 feet. The dip is about 26° north-westward.

Zone of *Monograptus convolutus* (*Ad_2*).—For the next 100 yards or so (equivalent to a vertical thickness of about 120 feet) there is a break in the continuity of the river-section, and only a part (a few feet) of this zone is exhibited. This portion lies in the floor of the river-course, and the rock can be seen only when the river is low. From such hand-samples I have extracted a single specimen of *Monograptus convolutus*, occurring in a slightly nodular pale bluish-grey mudstone with green ferruginous bandings.

Pale Grey Mudstones (Ad_3).—From the termination of the last zone up to the Rhyd-hîr Brook the bed of the Wye is floored by pale bluish-grey mudstones and flags. Some of these are banded with pale green or blue seams, but the whole group is extremely monotonous in its lithological characters, and is practically barren of fossils. Near the summit, however, the flags yield *Climacograptus normalis*, *Leptæna*, and *Orthoceras* sp. The total thickness of this division measures rather less than 250 feet.

Immediately succeeding the above is a great group of pale shales, the Rhayader Pale Shales (*C*), which are not exposed in the river itself at this point, but may be seen about 50 yards or so up the brook at the water-wheel of the Tannery. At this exposure graptolites are abundant in certain beds, from which the following fossils have been obtained:—

Monograptus Sedgwickii, Portl.	*Monograptus pandus*, Lapw.
—— —— var. *distans*, Portl.	—— *crassus*, Lapw.
—— *involutus*, Lapw.	—— *jaculum* (?) Lapw.
—— *lobiferus*.	*Climacograptus extremus* sp. nov.
—— *Becki*, Barr.	*Peltocaris aptychoides* (?) Salt.

It will be seen that this assemblage, considered as a whole, is very different from the collective fauna of the zones which we have traced up to this point. Only one species, *Monograptus lobiferus*, in the fauna of these Pale Shales occurs in the beds hitherto described. It is evident, therefore, even at first sight, that we are here dealing with a new rock-group, separated from the Gwastaden Group by an enormous extent of geological time. At this point, therefore, may be drawn the line marking the top of the Gwastaden Group.

Confining our attention to the typical section described in the preceding paragraphs, we see that here is a collective series of rocks over 1800 feet thick, apparently conformable from base to summit. This group—the Gwastaden Group—is underlain with apparent conformity by a group of Blue-black Shales, and overlain with apparent conformity by a group of Pale Shales. The Gwastaden Group itself includes grits, flags, and shales, the grits being thickest at the base. From the base the grits gradually thin out, and are replaced by hard blue-and-grey flags. These pass up in their turn into soft shales, and these again into a series of pale mudstones.

It is evident, judging from the included fossils, that the various divisions of the Gwastaden Group are closely bound together, for there is no break in the life-succession, but merely a gradual evolution from the base to the summit of the group. In the lowest rocks occur only the genera *Climacograptus* and *Diplograptus*. The Monograptidæ make their first appearance at about one-third the thickness of the group, measured from the base, and, in company with the Climacograptidæ and the Diplograptidæ, reach the topmost

beds. Between the Gigrin Mudstones (*Ad*) at the summit of the Gwastaden Group and the overlying Pale Shales (*C*) there is an almost complete break in the life-sequence, indicating a great lapse of time between the periods of deposition of the Rhayader Pale Shales above and the strata of the Gwastaden Group below.

The foregoing conclusions may be tabulated as follows :—

(*C*) **Rhayader Pale Shales.**

(Palæontological break.)

(*A*) **Gwastaden Group.**

	Feet.	
(*Ad*) Gigrin Mudstones.		
(Ad_3) Pale Grey Mudstones	250	510
(Ad_2) Zone of *Monograptus convolutus* / (Ad_1) Calcareous-Nodule Beds	260	
(*Ac*) Ddôl Shales.		
(Ac_3) Zone of *Monograptus fimbriatus*	150	600
(Ac_2) Zone of *M. cyphus*	200	
(Ac_1) Zone of *M. tenuis*	250	
(*Ab*) Dyffryn Flags.		
(Ab_3) *Diplograptus-modestus* Flags	300	530
(Ab_2) Rottenstone Beds	50	
(Ab_1) Micaceous Flags and Grits	180	
(*Aa*) Cerig Gwynion Grits		170
		1810

Cleaved Blue-black Shales.

(2) Confirmatory Sections.

(*a*) Dyffryn Wood and Woodlands.

About ½ mile south-west of our first traverse a very fair confirmatory section of the rocks is displayed in the sides of a small stream running from off Gwastaden. This stream rises some distance west of the Cairn, and crosses the Builth road to the west of Dyffryn Cottage. It joins the Wye below the road; and, if the section be continued through Woodlands House on the opposite side of the river, it affords a check on the complete succession as described in the foregoing pages. (See fig. 2, p. 85.)

Commencing our examination west of the Cairn, where the Cerig Gwynion Grits (*Aa*) rise to their greatest height above the valley, we find, as before, cleaved Blue-black Shales below them. The basement-grits are here about 200 feet thick. From the topmost bed of the grits to the northward there is a considerable break in the exposures along the stream itself; but here and there to the right or left isolated patches of the Micaceous Flags and Grits (Ab_1) may be seen peeping out from the bracken and gorse on the hillside. About 60 paces above the top of the wood, rocks once more become visible in force, and are fairly continuous down to the road. At the commencement of this

exposure there is no difficulty in recognizing the horizon, even at a first glance. The bright red or orange colour of the weathered surfaces is alone sufficient to convince the observer that he is in presence of the upper part of the Micaceous Flag and Grit Division (Ab_1). In addition, the occurrence of thin plates of grit, and patches of calcite in thin films, so characteristic of this division, may be noted. A fossil-band at the beginning of the exposure has yielded the following forms :—

Leptæna transversalis, Wahl.	*Orthis testudinaria*, Dalm.
Orthis biforata (?) Schloth.	*Dimorphograptus elongatus (?)* Lapw.

and from soft shales above the wood I have obtained *Diplograptus acuminatus (?)* and *Climacograptus normalis*. *Leptæna transversalis* is the commonest form in the fossil-band, and is usually found in a good state of preservation.

If any doubt be felt as to the horizon, this may be instantly removed on entering the wood; for on the banks of the stream the characteristic calcareous flags of the succeeding Rottenstone Beds may be observed (Ab_2). These, together with intermingled blue flags and nodular shales, extend down to the road, with a considerable breadth of outcrop, as their angle of dip very nearly coincides with the slope of the ground. From exposures at the roadside, some distance west of the stream, *Diplograptus modestus* and *D. longissimus* may be extracted. The dip of the beds averages about 35° north-westward.

North of the main road occurs a considerable gap in the section, representing a thickness of some 800 feet; and it is not until the river is crossed and the opposite bank ascended that any rock comes into view. On the east side of Woodlands House, and along the boundary-fence, a small stream has laid bare some 50 feet or so of strata, dipping at 21° into the hill. The exposures show red-weathered, dark-blue-banded shales, which yield the following fossils :—

Monograptus communis.	*Diplograptus tamariscus.*
—— *fimbriatus.*	—— *magnus.*
—— *gregarius.*	*Climacograptus undulatus.*
Orthoceras sp.	—— *rectangularis.*

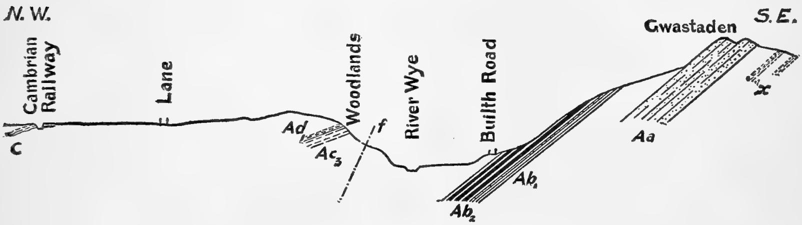
These species suggest the horizon of *Monograptus fimbriatus* (Ac_3), and, from the occurrence of *Climacograptus undulatus* and *Diplograptus magnus*, one would infer that this band is somewhere near the top of the zone. This can be easily proved; for at the top of the bank a few feet of mudstones, belonging to the Calcareous-Nodule Beds (Ad_1), are exhibited, with their characteristic blue lenticular markings; and in a small quarry at the side of the path above the house ferro-manganese nodules are of frequent occurrence. In the sides of the excavations for the house, on its north side, the following graptolites have been found :—*Diplograptus magnus*, *Climacograptus rectangularis*, and *Cl. undulatus*.

The ground is carpeted with turf north of the stream, and the rocks

of the Gwastaden Group are no longer visible. The Rhayader Pale Shales, however, are well shown in the Mid Wales Railway-tunnel; but they are barren of fossils.

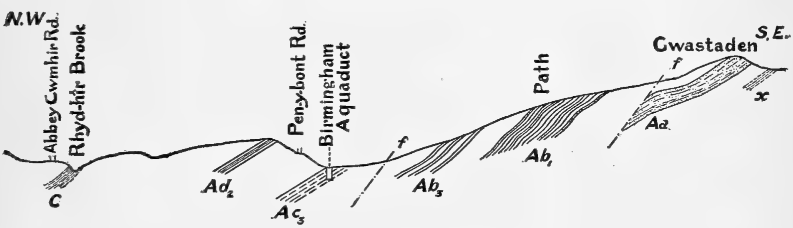
It will be seen that in this second line of traverse, with the exception of the break in the river-valley, the sequence of the beds corresponds well with that obtained in our first section. The

Fig. 2.—*Section through Woodlands from Gwastaden Cairn to the Cambrian Railway-line.*



[Approximate length = $1\frac{1}{4}$ miles.]

Fig. 3.—*Section from Gwastaden to Rhyd-hîr Brook.*



[Approximate length = 1 mile.]

C = Rhayader Pale Shales.
A = Gwastaden Group.
Ad = Gigrin Mudstones.
Ad_2 = Zone of *M. convolutus*.
Ad_1 = Calcareous-Nodule Beds.
Ac = Ddôl Shales.
Ac_3 = Zone of *M. fimbriatus*.
Ab = Dyffryn Flags.
Ab_3 = *D.-modestus* Flags.
Ab_2 = Rottenstone Beds.
Ab_1 = Micaceous Flags and Grits.
Aa = Cerig Gwynion Grits.
x = Blue-black Shales.
ff = Faults.

greater part of the Ddôl Shales, and the whole of the *Diplograptus-modestus* Flags, however, are missing, being apparently covered by the river-alluvium; moreover, only a fraction of the Gigrin Mudstone division (*Ad*) is displayed. A good part of these missing beds is exhibited in the section (fig. 3, above) described on the following page.

(*b*) Esgair-rhiw.

An excellent confirmatory section (fig. 3, p. 85) of the Gwastaden Group occurs in the brook west of Esgair-rhiw Farm, about a mile east of the typical section. The Cerig Gwynion Grits (*Aa*) at the crest of the hill are here again found to overlie cleaved Blue-black Shales, but reach a thickness of only about 100 feet. Descending towards the stream, we pass over a few exposures of the Micaceous Flags and Grits (Ab_1), dipping at 26° north-westward. A short north-and-south fault is next crossed, and we then enter the stream-section at the sharp bend to the west. In some carbonaceous bands in the blue-and-grey Micaceous Flags and Grits immediately below the hedge *Climacograptus parvulus* and *Cl. normalis* may be detected; and some distance farther down *Diplograptus acuminatus* also occurs. From the first hedge above the path leading to Esgair-rhiw Farm to about 100 feet below it, there is a fairly continuous exposure of the red-weathered flags and shales. These yield the fossils enumerated above, together with *Diplograptus modestus (?)* and *Orthoceras* sp. The dip of the beds is about 30°.

A gap in the section probably takes the place of the Rottenstone Beds, for the grey *Diplograptus-modestus* Flags (Ab_3) are well shown immediately above the hedge at the summit of the copse, and for some hundred yards or so below. Immediately south of this hedge, the flags contain *Diplograptus modestus*, and from a calcareous band about 5 or 6 yards north of it I have procured

Orthis elegantula, Dalm.
—— *testudinaria (?)* Dalm.
Favosites gothlandica, Fougt.
Stenopora (*Favosites*) *fibrosa*, Goldf.
Atrypa sp.

On the flat ground, and for a length of 300 or 400 yards within it, not a patch of rock makes its appearance. A strike-fault (shown in fig. 3, p. 85) crosses the centre of this blank, and at the line of section has a downthrow of about 200 feet.

In the trench for the Birmingham Aqueduct along the banks of the stream south of Pen-y-bont road, about 300 yards east of Cefn-Ceidio Hall, an excellent section of the Ddôl Shales (*Ac*) was laid open. The fossils obtained from the blue-banded shales in the sides of the trench were in relief and in perfect preservation. The forms detected included *Monograptus communis*, *M. fimbriatus*, *M. argutus*, *Diplograptus tamariscus*, *D. magnus*, *D. sinuatus*, *Climacograptus rectangularis*, *Cl. undulatus*, and *Cl. normalis*. All these species are characteristic of the summit of the Zone of *Monograptus fimbriatus* (Ac_3).

The overlying Mudstones were not seen in the cutting itself, but they are well exposed on the northern bank of the stream east of Cefn-Ceidio.

As this section is continued in a north-westerly direction through the junction of the Pen-y-bank and Pen-y-bont roads, the ground

rapidly rises; and along the crest, both above and below the road, the rocks of the Zone of *Monograptus convolutus* (Ad_2) form a prominent ridge across the fields. They consist of blue-banded hard blue mudstones and shales with brown sandy bands, and contain the following fossils:—*Monograptus convolutus*, *M. argutus*, *M. crenularis (?)*, *M. communis (?)*, *Climacograptus normalis*, and *Diplograptus* sp.

Beyond the ridge to the northward the ground falls towards Rhyd-hîr Brook, where a shallow glen has been cut through the basement-beds of the Rhayader Pale Shales (*C*). These rocks are highly cleaved in the banks of the stream, and graptolites are extracted only with difficulty, but among others I have identified *Monograptus crassus*,—a sure indication that we are somewhere near the same horizon as that of the Tannery beds.

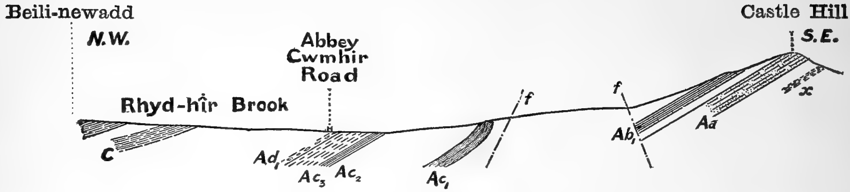
(b) *Supplementary Sections through Castle Hill and the Eastern Portions of the District.*

(1) Castle Hill.

The three previous sections may be fairly said to cover the central portions of the Rhayader District. They show that the general succession on the flanks of Gwastaden Hill and in the floor of the Rhayader Valley is, to all intents and purposes, constant from one end of the range to the other. At the eastern extremity of Gwastaden the hill-slopes dive suddenly down into the valley of the Black Brook, which may be taken as marking the line that separates the central and eastern portions of the area under description. The sluggish Black Brook winds through a Drift-covered valley, in which no rock is visible. In the line of strike of Gwastaden, however, rises on the north side of the brook a small wooded knoll about ½ mile in length, to which the name Castle Hill is given. Through the crest of this the traverse figured on p. 88 is taken (fig. 4).

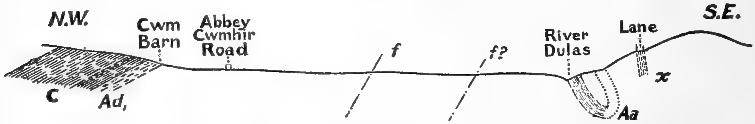
The exposures on the summit are poor; and only a few ribs of rock can be seen projecting through the short turf on the hillside immediately south of the cairn. The rock consists of impure, thin grey grits and soft shales. The grits seldom exceed 6 inches in thickness, and are curiously striped with wavy black and brown bands. The shales are soft; sometimes flaggy, and all highly cleaved. They are light brown, and present a peculiar speckled appearance. The beds weather brown as a rule, but are often coated with iron-oxide. So different is this rock-group from anything that has been seen in the Rhayader Valley, that one might doubt whether these strata belong to the Gwastaden Group; but as they lie in the same line of strike as the Cerig Gwynion Grits, have the same north-westerly dip, and, moreover, are underlain by the same cleaved Blue-black Shale that is always to be found in a corresponding position on Gwastaden Hill, one may safely assume that they

Fig. 4.—*Section from Castle Hill to Beili-newadd.*



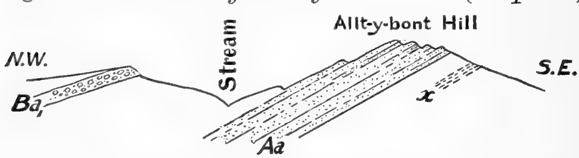
[Approximate length = $1\frac{1}{4}$ miles.]

Fig. 5.—*Section from Vaynor Farm to beyond Cwm Barn.* (*See p. 90.*)



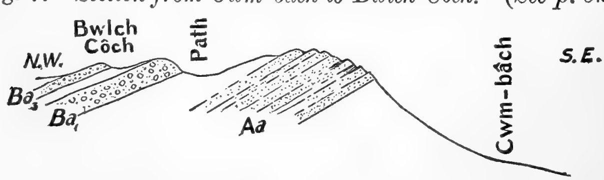
[Approximate length = 1 mile.]

Fig. 6.—*Section through Allt-y-bont Hill.* (*See p. 91.*)



[Approximate length = $\frac{3}{4}$ mile.]

Fig. 7.—*Section from Cwm-bâch to Bwlch Côch.* (*See p. 92.*)



[Approximate length = $\frac{3}{4}$ mile.]

C=Rhayader Pale Shales.
B=Caban Group.
Ba_3=Upper Conglomerate.
Ba_1=Lower Conglomerate.
A=Gwastaden Group.
Ad=Gigrin Mudstones.
Ad_1=Calcareous-Nodule Beds.
Ac=Ddôl Shales.
Ac_3=Zone of *M. fimbriatus.*
Ac_2=Zone of *M. cyphus.*
Ac_1=Zone of *M. tenuis.*
Ab=Dyffryn Flags.
Ab_2=Rottenstone Beds.
Ab_1=Micaceous Flags and Grits.
Aa=Cerig Gwynion Grits.
x=Blue-black Shales.
ff=Faults.

are shaly representatives of the Gwastaden basement-beds. Further, we have already seen that the grit-group thins out eastward, and it seems but natural to suppose that, concurrently with an attenuation of the whole of the division, the individual grit-beds also should become attenuated. Fossils are extremely rare. Badly-preserved specimens of the genus *Climacograptus*, however, may be detected occasionally in the interbedded shales. The thickness of the whole of the basement-grits here is about 100 feet.

Carrying on the traverse down the slope of the hill, little or no rock makes its appearance on the exact line of section, but at the sides of the path from Upper Bwlch to Little Castle impure grits and speckled soft brown flags and shales are fairly continuously exposed. In the absence of fossils, however, it is difficult to make out the divisions recognized in the typical sections. From some calcareous flags and shales in the old quarry immediately above Upper Bwlch I have extracted

Tentaculites anglicus (?) Salt.	*Leptæna transversalis.*
Atrypa marginalis (?) Dalm.	—— *rhomboidalis*, Wilck.
Orthis elegantula.	*Petraia elongata (?)* Phill.
—— *testudinaria.*	*Climacograptus* sp.

The exact horizon of these beds is uncertain; the foregoing fossils, however, agree so well with those obtained from the Gwastaden streams that there is little doubt but that the rocks belong to the Dyffryn Flags (*Ab*).

From the foot of the hill the section follows a small stream draining into Rhyd-hîr Brook. The whole of the low-lying ground in this area is thickly covered with Drift; and the stream shows no rock-exposures until we are within 100 yards or so of the ravine at the bottom of the valley. Here a thickness of about 50 feet of scarlet and orange-weathered flags and shales of the *Monograptus-tenuis* Zone (Ac_1) has been washed bare. The flags reach about 2 inches in thickness, and are blue or grey in colour. The blue shales are blue-banded, weathering occasionally to ashy-white.

I have doubtfully recognized *Monograptus tenuis* in these shales; but the graptolites are badly preserved, and cannot be identified with certainty. The dip varies from 90° at the southern end of the exposure to 29° north-westward at the northern end. The strike-fault, mentioned as passing through the Esgair-rhiw section (p. 86), crosses the stream immediately above the exposure; and it is probable that the proximity of this fault is responsible for the beds being tilted up at so great an angle.

In Rhyd-hîr Brook itself, south of the road-bridge, occurs an exposure of the overlying group. About 150 feet below the bridge a few feet of the Zone of *Monograptus fimbriatus* (Ac_3) is shown. The shales yield *Monograptus triangulatus*, *M. communis*, *Climacograptus rectangularis*, and *Orthoceras* sp.

In the same line of strike, about 300 yards to the westward, the overlying Calcareous-Nodule Group (Ad_1) may be found in

the brook resting on the *M. fimbriatus*-shales. The latter contain *Monograptus fimbriatus*, *M. communis*, *M. attenuatus*, *Diplograptus sinuatus*, *D. magnus*, *D. tamariscus*, *Climacograptus rectangularis*, and *Orthoceras* sp. A small patch of the Nodule Group may also be seen under the Abbey Cwmhir road-bridge on the line of section.

A good section of the Rhayader Pale Shales (*C*) is displayed in the stream some 300 or 400 yards above the road, and again east of Beili-newadd Farm. The rocks do not closely resemble their equivalents at the Tannery. Thin impure grit-bands occur in places, from which *Monograptus priodon*, Bronn (var.) may be extracted. An examination of the fossils obtained from the same beds in a stream to the eastward still shows that, as in the case of our typical section, the graptolitic faunas of these Pale Shales and the underlying rocks are absolutely distinct.

(2) Vaynor.

The most easterly section, which I propose to describe, passes down the narrow valley separating Castle Hill from Llan Gôch. This, indeed, is the last section along which any succession may be made out; for, as we extend our examination eastward, the sections are obscured by Drift; moreover, the divisions which were so distinctly separable in the typical section cannot here be recognized. Again, the rocks are folded and faulted to a considerable extent; and I do not profess to understand thoroughly the structure of this easternmost area.

On the line of section itself shaly representatives of the Cerig Gwynion Grits (*Aa*) occur in the Dulas Brook below Great Vaynor Farm, dipping steeply south-eastward (see fig. 5, p. 88). They resemble somewhat the same group as developed on the summit of Castle Hill: but here the shales and flags predominate. The underlying Blue-black Shales may be seen in the hedge-banks of the lane leading up to Great Vaynor Farm. A good exposure of the flags of the Zone of *Monograptus cyphus* (Ac_2) has been laid open in the road-cutting east of Cwm Barn. These rocks contain no fossils, but their lithological characters are so well marked that their exact horizon can be assigned to them immediately. On the north side of the farm a few feet of dark brown-weathering, nodular grey flags and shales (Ad_1), with small nodules of carbonate of lime, may be observed; and from certain blue bands in the shales the following fossils have been obtained:—*Monograptus communis*, *M. argutus*, *Diplograptus* sp., *Climacograptus rectangularis*, and *Cl. normalis*.

Immediately above this group lies the representative of the Rhayader Pale Shales (*C*) with *Monograptus priodon*, etc. At the base is a considerable thickness of arenaceous rock, a few beds of which are crammed with brachiopoda. A description of these shelly bands will be given later (see p. 121).

Referring to the typical section it will be seen that in the Wye Valley, between the Ddôl Shales and the Rhayader Pale Shales, there is a vertical thickness of rock of over 500 feet, and

the Pale Shales rest on Pale Grey Mudstones (Ad_3). In the Castle-Hill section this thickness has diminished to about 250 feet, and in the Vaynor section the Upper Pale-Shale Group rests upon the lowermost beds of the Calcareous-Nodule Group—the Pale Grey Mudstones (Ad_1) and the Zone of *Monograptus convolutus* (Ad_2) having disappeared. It would seem then, if no fault intervenes to cut out these missing beds, that the Rhayader Group rests irregularly upon the Gwastaden Group. Such indeed is the case, and, as will be shown later, no fault is likely to exist, a marked unconformity separating the two series. The missing beds are not faulted out, but are merely overstepped by those of the overlying group.

(c) *Exposures in the Western Areas.*

East of the River Elan, in the central and eastern portions of the district already described, the interpretation of the sections becomes a simple matter, for, as we have seen, the confirmatory sections show the same general succession in the zones of the Gwastaden Group as in the typical section itself. But as we cross the Elan into the western areas matters wear a very different aspect; and bearing in mind the comparative simplicity of the geology of the area already examined, one is at first perhaps somewhat startled by the introduction of a new set of phenomena, strikingly contrasted with everything hitherto encountered.

(1) Allt-y-bont.

In dealing with this portion of the Rhayader District, perhaps no better method can be adopted than that which has already been used in the western areas; namely, of sketching a series of parallel sections, in order to show the arrangement of the beds as we advance from point to point along the strike.

Commencing at the eastern limit and working westward, the first section is shown through Allt-y-bont Hill (fig. 6, p. 88). Here the Cerig Gwynion Grits (Aa) are exposed in the form of magnificent crags, which swing down from the summit of the ridge into the gorge of the Wye: the total thickness of these beds at this point is about 300 feet. They rest, as before, upon cleaved Blue-black Shales, and are followed by the overlying Micaceous Flags and Grits (Ab_1), a few patches of which flank the northern side of the hill.

On crossing the stream, however, and ascending the rise below Pen-y-rhiw, one is suddenly confronted with a vertical cliff formed of massive conglomerate (Ba_1), some 50 feet thick, occupying a position which corresponds apparently with that of the Rottenstone Beds. This conglomerate runs rapidly downhill, and ends abruptly at about 100 yards north of the section-line. Before dealing with the cause of the incoming of this new conglomerate-group, it will be expedient, first of all, to examine and describe the remaining sections.

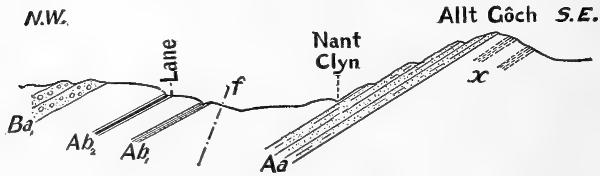
(2) Corn Gafallt.

About $\frac{1}{2}$ mile west of the last section the Gwastaden basement-grits thicken out to some 600 or 700 feet (fig. 7, p. 88); and the conglomerate-bed approaches to within an horizontal distance of 100 yards or so of the top of the grit-group.

(3) Allt Gôch.

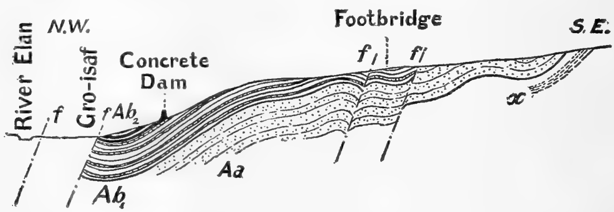
The Cerig Gwynion Grits may be followed westward for nearly a mile along their line of strike. Their outcrop along Corn Gafallt Hill covers a breadth of between 400 and 500 yards;

Fig. 8.—*Section from Allt Gôch towards Ty'n-y-graig.*



[Approximate length = $\frac{7}{8}$ mile.]

Fig. 9.—*Section along the Nant-y-Gro.* (*See p. 93.*)



[Approximate length = 1 mile.]

B = Caban Group.
Ba$_1$ = Lower Conglomerate.
A = Gwastaden Group.
Ab = Dyffryn Flags.
Ab$_2$ = Rottenstone Beds.
Ab$_1$ = Micaceous Flags and Grits.
Aa = Cerig Gwynion Grits.
x = Blue-black Shales.
ff = Faults.

and if the group be traversed in the direction of the dip, the successive beds may be observed rising in well-marked mounds one after another, suggesting the huge billows of a stormy sea. After crossing the blank formed by the marshy flat of the River Dulas, the grits may be seen sweeping steadily up to the summit of Allt Gôch Hill, where they are once more shown in force, resting as usual on the highly-cleaved Blue-black Shales. A section from the highest point towards Ty'n-y-graig (fig. 8) shows the thickness of these grits to be about the same as in our last traverse, but a strike-fault cuts out a portion of this group and the overlying

Micaceous Flags and Grits (Ab_1). A small exposure of the uppermost beds of the latter division has been swept bare in a small gully about 150 yards south of Ty'n-y-graig. The rock shows intermixed blue flags and shales, weathering to a brilliant scarlet and orange. The flags are striped with thin white grit-bands and lustrous calcite-films may be noticed in certain beds. I have obtained from here a few graptolites (*Diplograptus* sp.) and a specimen of *Orthoceras*. About 200 yards higher up the hill, approximately in the same line of strike, certain shales lining the sides of the path to Gro-isaf yield *Climacograptus parvulus*, a fairly conclusive index of the true horizon of these beds; and any uncertainty is dissipated on continuing the section, for blocks of the soft brown beds of the Rottenstone Group (Ab_2) strew the sides of the lane immediately above Ty'n-y-graig Cottage. About 150 yards farther on, the Conglomerate-bed (Ba_1) is again met with.

(4) Nant-y-Gro.

The fourth and last section is by far the most interesting, as regards the Gwastaden Group, that is to be found in the western areas. For, not only are the exposures continuous for nearly a mile, but they show that even at a distance of over 4 miles from the typical section the divisions of the lower portions of the Gwastaden Group have maintained, to all intents and purposes, their lithological characters, and after a careful traverse can be separated out. The section figured here (fig. 9, p. 92) is taken down the Nant-y-Gro, which discharges its waters into the Elan, about $\frac{1}{4}$ mile below its confluence with the Claerwen.

The rocks in this area are much faulted and folded, but with detailed measurements of the dip the beds can be fairly well pieced together and the true succession determined. From Allt Gôch Hill the Cerig Gwynion Grits (Aa) are easily traced westward through Crugiau Bâch, and, after a slight dislocation, make their appearance on the right bank of Nant-y-Gro, whence they may be carried on by the eye to the bold terraces of Gro Hill. We again find the cleaved Blue-black Shales underlying the grits in the Nant-y-Gro itself, some 400 or 500 yards above the ford. Some distance down, the grits appear in the form of an anticline; and immediately below the ford a strike-fault brings down the overlying Micaceous Flags and Grits (Ab_1). In the latter group, however, the individual grit-beds are much thicker than one has been accustomed to find hitherto. From a few flaggy beds in the basement-grits well-preserved specimens of *Climacograptus normalis* may be extracted.

Below the footbridge, another fault running north-north-east and south-south-west cuts out a considerable thickness of rock, the strata between the dislocations lying in a small syncline. The rocks are found to be somewhat crumpled and folded farther down stream, and, in consequence, cover a greater breadth of outcrop; and thus it is not until we come within about 200 yards of the concrete dam, which

has been built for supplying the Elan Village with water, that the red-weathered flags at the top of our second division (Ab_1) make their appearance. I have not discovered fossils in these beds above the dam; but immediately below the dam *Diplograptus longissimus*, *D. modestus (?)*, and *Climacograptus normalis* were detected. These graptolites occur also in the loose blocks which have been removed from the site of the dam-trench, and fragments of rottenstone may be seen in the loose scree on the banks of the brook; and on the east side of the path above Gro-isaf beds of this material can be seen *in situ* dipping into the hill. The unmistakable appearance of this characteristic rock and the occurrence of the typical fossils point conclusively to the horizon of the Rottenstone Beds (Ab_2).

No further exposures are visible after reaching the river-alluvium below Gro-isaf. A north-and-south fault passes through Gro-isaf, crosses the slope above the crest of Craig Fawr in a well-marked groove, and joins the Abernant Fault, somewhere in the river-flat. It will be more expedient, however, to deal later with the ground lying to the west of these dislocations.

Having now examined those portions of the Gwastaden Series that lie within the western area, we are in a position to compare them with their equivalents in the central and eastern districts.

One fact is evident, that in the western area a fresh set of deposits, differing entirely from any that we have seen before, has made its appearance. The lowest bed in this new group, which we have, as yet, merely touched upon, is a conglomerate, which crosses irregularly over the lower zones of the Gwastaden Group. In our first section through the western area this conglomerate was found on the horizon of the Rottenstone Beds (Ab_2). In the second it approached within a short distance of the Cerig Gwynion Grits (Aa). Above Ty'n-y-graig it overlies the *Diplograptus-modestus* Flags (Ab_3); and in the Nant-y-Gro the bed has disappeared. A glance at the map (Pl. VII) shows that this conglomerate-mass (Ba_1) creeps round from a north-easterly and south-westerly strike into a north-and-south line; and on the west side of Cnwch Hill it reposes in beds high up in the *Diplograptus-modestus* Flags (Ab_3), and approaches nowhere near the Nant-y-Gro. Now, two explanations only can be given for the irregular position of this new group:—(1) There may be a thrust-fault at the base of the conglomerate, the plane of which, in order to bring about the peculiar outcrops of the beds, must be nearly horizontal; or (2) there may be an unconformity between the Gwastaden Group and this new conglomeratic series. For reasons which I propose to bring forward later, the first cannot exist, and it will be shown that this new bed—the Caban Conglomerate—rests unconformably upon the Gwastaden Group.

(d) *Additional Notes on Supplementary Exposures.*

Before summarizing my observations of the Gwastaden Group as a whole, it is necessary to fill up some important gaps in the typical sections. The missing beds are found in several minor exposures, which occur between the typical section-lines already described, but they have not been mentioned hitherto lest our minds should be confused as to the general order of the beds. Now that this general order has been established, I turn to the description of these minor sections, with the view of giving the complete succession, from bottom to top of the series.

(1) Cerig Gwynion Grits.

This group (*Aa*), as I have already stated, is most completely exhibited in the Cerig Gwynion Crags, after which the beds are named. At the foot of these crags a quarry was opened for supplying a part of the Birmingham Waterworks with building-stone, and an interesting section is here exhibited. In the quarry itself the group has a total thickness of over 230 feet. The typical rock, which is found in beds running up to 10 feet in thickness, is here a very dense, tough, hard quartzose grit or grauwacke. The colour varies from bluish-grey to greenish-grey. Occasional beds of coarse rock, with white quartz-pebbles about the size of a pea, are to be found on certain horizons, and a lenticular bed of conglomerate occurs at about two-thirds of the thickness up the group. This is a somewhat calcareous bed, with pebbles averaging about 1 inch in diameter. Its maximum thickness in the quarry is only about $2\frac{1}{2}$ feet; but it is a remarkably persistent bed, and may be traced westward on the opposite side of the river for a distance of over $1\frac{1}{2}$ miles.

Thin dark-blue slates interbedded with the grits form well-defined platforms in the cliff, giving a rugged and scarped appearance to its face. These bands yield *Climacograptus normalis*, and this species and its variations only: no traces of Diplograptidæ or Monograptidæ having been detected by me at any time. Microscopic sections of the grits show the constituent grains to be sub-angular or rounded in form, and to consist mainly of quartz. Fragments of vein-quartz and felspar are not uncommon; more rarely bits of felsite, microgranite, andesite, basic rocks, and slates occur. Mica may be found in some quantity in certain beds, but it forms by no means a common constituent of the rocks, considered as a whole.

As the group is followed westward, we have already seen that it rapidly thickens out to more than twice its normal thickness at Cerig Gwynion. This augmentation may be due partly to strike-faulting, but only in a small degree; for complete sections through the group fail to show any repetition of the beds. To the eastward the conditions are reversed, for the group thins down to something like 100 feet at the eastern limit of the district. The individual

layers also dwindle from massive 10-foot grits to thin, impure grit-flags, never exceeding 6 inches in thickness, and interstratified with soft dark shales. Such phenomena would lead one to suppose that the waters in which these grits were deposited were of greater depth in the east than in the west; or, in other words, as we trace the group westward we are approaching ever closer to the old land-surfaces. If so, we should expect the grits to become coarser, and finally, perhaps, to be replaced by conglomerates. Such may be the case; but I have not yet had opportunities of satisfying myself on this point.

The Blue-black Shales that underlie these Cerig Gwynion Grits in the central and western areas show no signs of passing up gradually into the basement-beds of the overlying series. High up above the Builth road, the bottom-grits are seen with this dark shale below them; and so sudden is the change from massive soft black shales to arenaceous beds that one might imagine a fault to exist between the two groups. A most interesting character of this lower series is the double cleavage that can be traced in some of the exposures below Cerig Gwynion. One of these cleavage-directions lies parallel to the normal cleavage of the Gwastaden Group, that is, parallel to the strike of the rocks. The other, however, runs at an acute angle to this, in a north-north-easterly and south-south-westerly direction. The existence of this second cleavage suggests that the shales are of much greater antiquity than the grits, being cleaved before the grits were deposited. This would involve a time-break between the two groups, and possibly an unconformity; but there seems to be no evidence in support of the latter hypothesis. The Cerig Gwynion Grits in the Rhayader District always overlie these dark shales, and if such an unconformity exists between the two series it can be only of minor importance. Again, at the eastern limits of the district, where the grits have dwindled down to extreme tenuity, there seems evidence of a passage upward from these Blue-black Shales to the Gwastaden Group, for on Llan Gôch Hill it is almost an impossibility, in the field, to say where the one group ends and the other begins.

No fossils have been detected in these dark shales, as developed in the immediate neighbourhood of Rhayader. South and east of the district, the same general type of rock extends for some 5 or 6 miles,—often intermixed with grits and sandstones, and occasionally with beds of conglomerate. In the vicinity of Nantmel and Hirfron, some 4 or 5 miles east of Rhayader, certain dark seams in the arenaceous rocks yield *Diplograptus foliaceus*, Murch. and other graptolites. There is a complete absence of Monoprionidian forms; a fact that points to these rocks being of greater antiquity than those of the Gwastaden Group.

(2) Dyffryn Flags.

In addition to the areas that have been already described, these flags (*Ab*) extend over a great part of the Elan Valley. They make

up the magnificent crags of Craig-y-Foel; they may be seen in the new road-cuttings round the hill, and can be followed past Careg-ddu up to Dol-Folau farm. They constitute the main mass of the wooded hills behind Cwm Elan, Cwm Coel, and Nant Gwyllt; while above Dol-y-Mynach the Cerig Gwynion Grits (*Aa*) emerge in the form of a huge dome, extending over a vast area of moorland to the westward.

The slates are harder, more granular, and more micaceous than their equivalents in the Rhayader Valley; and, in addition, are very highly cleaved. This cleavage appears to have been made use of, for several quarries along the banks of the Claerwen have been opened for the purpose of extracting roofing-slates. Where it is possible to obtain recognizable fossils from the rocks the forms are always found to be Diplograptidæ or Climacograptidæ—genera characteristic of this division.

In the Rhayader Valley the Dyffryn Flags are well exposed in the sides of the Builth road from Gigrin Prysyg to the Glyn. In the last-named locality they are best seen in the river-course east of the railway-bridge, and will be found to contain very well-preserved specimens of *Diplograptus modestus* and *Climacograptus normalis*.

In their lowest division, where the flags are interbedded with shales, a series of quarries have been opened out along the slope of Gwastaden. The grits, which may be extracted with little difficulty, have been used in building the various farmsteads in the immediate neighbourhood; and, in combination with the stone from Allt-y-bont, have been largely employed in the construction of many of the buildings in the town of Rhayader.

At Pen-y-bank the Rottenstone Beds (Ab_2) form the crest of the ridge above Upper Downfield Farm; but they have been so faulted that they are now turned at right angles to their original strike, and dip westward. The isolated block, which has been pushed up through the overlying strata, can be followed to the road below to within 150 yards of the Zone of *Monograptus fimbriatus* (Ac_3), and is here cut out by the strike-fault already mentioned.

A few patches of Dyffryn Flags are visible on the flanks of Castle Hill, and in the sides of the slope above Great Vaynor Farm; but their general appearance and lithological characters have altered to such an extent that it is almost impossible to separate out the subdivisions.

(3) Ddôl Shales.

The lowermost portion of this group, the Zone of *Monograptus tenuis* (Ac_1), is exposed in three places only—on the River Wye, in the Builth road, and in the banks of the lane leading to Cae-newydd. In every case the section is a poor one, but as the topmost beds closely resemble those at the base of the subdivision, and as *Monograptus tenuis* is absolutely confined to them, we can have no hesitation in making this a distinct zone.

An admirable section of the succeeding band may be examined in the stream south of the Workhouse. A very fossiliferous set of shales at the first hedge above the road contains *Monograptus cyphus*, *M. revolutus (?)* Kürck., *M. attenuatus*, *M. Sandersoni (?)*, and *Climacograptus rectangularis*.

Of the highest division—the Zone of *Monograptus fimbriatus* (Ac_3), little more can be said. The limestone-bands of the Wye section have not been detected elsewhere. It is probable that they thin out eastward and westward, and that they are of merely local occurrence; but with the information so far obtainable it is impossible to say definitely whether this is the case. A tunnel on the Birmingham Aqueduct, driven through the high ground above Lower Downfield House, cut a complete section through the upper shales (Ac_3). Only one fossiliferous zone in this tunnel, however, was detected; and this proved to be a series of thin carbonaceous banded grits containing small seams of iron-pyrites in the form of diminutive globules—a characteristic of the shales yielding *Monograptus triangulatus* in the Wye section. In the grits occur *M. triangulatus*, *M. gregarius (?)*, *Diplograptus tamariscus*, *Climacograptus normalis*, *Cl. rectangularis*, and *Cl. phrygionius (?)* Törnq.

(4) Gigrin Mudstones.

These are well shown in the lane leading to Ddôl Farm, and in the fir-copse below. The Birmingham pipe-trench runs through this plantation; and, when opened, showed an excellent section which enabled me to obtain a fair idea of the rocks of the group.

At the bottom of the copse the Calcareous-Nodule Beds (Ad_1) are exposed. These were found to be overlain by about 60 feet of hard metallic-weathering, blue-banded, blue and grey mudstones. Some of these blue bands are highly fossiliferous and yield *Monograptus convolutus*, *M. nuntius*, Barr., *M. lobiferus*, *M. Nicoli*, Harkn., *M. inopinus*, Törnq., *M. gemmatus (?)* Barr., *M. crenularis*, *M. argutus*, *M. Proteus*,[1] Geinitz var., *Diplograptus bellulus*, Törnq., *D. tamariscus*, *Climacograptus normalis*, and *Cl. undulatus*. Ferro-manganese nodules are not uncommon; and small flat nodules of carbonate of lime also occur. The chief features of the zone, however, are the blue bands and the dark-brown metallic-weathering surfaces. The former gradually die out as we ascend into our last zone (Ad_4), which is, unfortunately, to all intents and purposes destitute of fossils.

A good confirmatory exposure of these Gigrin Mudstones has been excavated in the lane, and in the old quarries above Glan Elan. From some blue-banded shale at the southern end of the lane *Monograptus lobiferus* and *M. Nicoli* may be extracted.

Identical rocks are exhibited in a small quarry about 100 yards north-west of Gigrin Farm, with *Monograptus convolutus*, *M. Proteus* var., *M. crenularis*, *Diplograptus tamariscus*, *Climacograptus normalis*, and *Cl. undulatus*.

The relative hardness of this zone renders it exceedingly useful

[1] See C. Lapworth, Geol. Mag. 1876, pl. xiii, fig. 4 e.

for following out in the field, as it forms a prominent ridge right across the country. The ground falling away on both sides, it stands out for a length of over 3 miles as the highest ground in the lower parts of the Rhayader Valley. In the gorge south of Cefn-Ceideo Hall there is a complete section of the Calcareous-Nodule Group (Ad_1) up to the base of the *Monograptus-convolutus* Zone (Ad_2). This section shows the division to have a thickness of about 200 feet.

No further exposures of the upper bands of the Gigrin Mudstones occur east of Lower Downfield, for as they approach the eastern limit of the district they are gradually overlapped by the Rhayader Pale Shales (C); and at Cwm Barn, only a few feet of the basement-beds of this mudstone-group peep out from beneath the rocks of the overlying series.

(e) *Summary.*

We are now enabled to summarize our investigation of the Gwastaden Group. It is seen to its best advantage in the Wye Valley, where it reaches a thickness of over 1800 feet; while from 1 to 3 miles to the westward only from 700 to 900 feet is exposed. The various subdivisions of the group, so well shown in the Wye Valley, can be scarcely recognized in the easternmost portion of the district; but when followed westward they may be separated out, to as far as 4 miles from our first typical section. The grits at the base of the series rapidly thicken out when followed westward, and become greatly attenuated in the opposite direction. The upper divisions, however, maintain their thickness fairly well throughout the district. In the Wye Valley proper, the whole group is overlain irregularly by a series of pale shales — the Rhayader Group (C).

West of the River Elan, a thick conglomerate-group is found resting unconformably upon the lower divisions of the Gwastaden Group. The next problem is to determine the relations existing between these two overlying groups: which is the older, and which the younger; and how they are stratigraphically related one to the other.

(B) The Caban Group.

This most interesting group, which we have as yet barely touched upon, is met with only in the western half of the district. Roughly speaking, it may be said to lie within the curve of the Elan, between Caban Cóch and the Elan's confluence with the Wye. It is never found north of this stretch of the river, except in one small area; nor is the smallest exposure to be seen to the eastward. Its outcrop extends over a length of only 2 miles, with an average breadth of from $\frac{1}{4}$ to $\frac{1}{2}$ mile. Yet, notwithstanding the relatively small area of country occupied by this group, the included rocks, whether considered as a whole, or bed by bed, are by far the most interesting in the district. They are best exhibited at Caban Cóch, some 3 miles west of Rhayader. In this gorge,

after which the group is named, its beds are exposed in magnificent cliffs, almost vertical for some 600 or 700 feet on both sides of the river; and from the bottom of the gorge the appearance of these great crags piled one above the other up to the sky-line is a striking spectacle. It is, indeed, one of the finest examples of rugged scenery within the district.

(a) *Typical Section at Caban Côch.*

Cnwch Hill, which lies south of the Caban-Côch gorge, is made up of these Caban rocks in the form of a syncline; taking, therefore, a traverse over its heights we shall have the benefit of a repeated succession. Furthermore, by extending the section across the Elan to the north side of the river where the beds are again exhibited, we shall cross the series no less than three times; and in this manner we ought to gain a very fair knowledge of its subdivisions.

(1) Caban Conglomerates (*Ba*).

Lower Conglomerate (Ba_1).—Commencing our section (fig. 10, p. 104) some 300 or 400 yards above Ty'n-y-graig, we find overlying the Dyffryn Flags a group of grey and bluish-grey grits and conglomerates (Ba_1). Some of the beds are very massive, averaging 10 to 15 feet in thickness. Freshly-fractured surfaces of the unweathered rock, and sections under the microscope, show the material to be highly siliceous, with an addition of a certain amount of felspathic matter. The felspar-paste decomposes generally to a considerable depth, sometimes to as much as 18 inches, leaving a soft, rotten, brown or ferruginous rock: from which, if it be conglomeratic, the pebbles may be easily removed by the fingers. The felspathic grains, in the disintegrated rock, take the form of white and ochreous blebs—very prominent, as a rule, on fractured surfaces—giving the rock a peculiar oolitic appearance. The grains of the matrix are somewhat coarse, angular to subangular in form, consisting chiefly of fragments of grits, quartz, vein-quartz, quartzite, mica, slate, and felspar, with rarer pieces of acid and basic igneous rocks. The pebbles are fairly well rounded; and are, with the exception of the mica, made up of the materials above mentioned. The commonest pebbles are those of grit and vein-quartz. In the lower beds, fragments of the former occur up to 6 inches or so in diameter. The largest blocks consist mainly of slate. These are found generally in irregularly-shaped masses more than a foot long, but they are by no means of frequent occurrence. Next in order of size and number are pebbles of white quartz, quartzite, and felsite, which are rarely found to exceed 2 or 3 inches in diameter. The grit-fragments closely resemble those of the Cerig Gwynion Grits, but it is impossible to say definitely whether they were derived from those rocks. The included slates are certainly fragments of the underlying Dyffryn Group. They are, however, too cleaved to yield graptolites. Considered as a whole, these Caban Conglomerates are so distinctive in their general characters, and so different from the Cerig Gwynion Grits, that the two rocks should

never be confused in the field. The total thickness cannot be estimated at this point, for a cross-fault cuts out some of the topmost beds: it is probably not less than 150 feet.

Intermediate Shales (Ba_2).—Succeeding the Caban Conglomerates is a thick mass of highly cleaved, micaceous blue shales (Ba_2). Only a few scattered patches, unfortunately, can be seen. They show the shales to be blue-banded and occasionally striped with thin arenaceous layers. The shales weather to a brilliant red, a coloration which forms a characteristic feature of the group. The thickness is between 200 and 300 feet.

Upper Conglomerate (Ba_3).—The shales are followed by a second conglomerate-and-grit group. This differs from the lower conglomerate, chiefly in the predominance of white vein-quartz-pebbles. The larger fragments are, as a rule, of grit and quartzite: the smaller being of felsite. There seems to be, in addition, a certain amount of manganese in the composition of the matrix, which gives rise to a pronounced purplish-brown weathering at certain horizons. Fragments of various iron-ores also may be seen in microscopic sections of the rock. The thickness at this point is about 100 feet.

(2) Gafallt Beds (Bb).

Monograptus-Sedgwickii Grits (Bb_1).—The next division is remarkable for the extraordinary contrast which it presents with the underlying group. It may be described as a regularly alternating series of fine-grained grey flags and smooth pale grey-and-green shales. The grits contain a fairly high percentage of felspar, in addition to the quartzose material. They are striped with carbonaceous bands, and in places appear to be false-bedded. Commencing with a thickness of about 2 feet, they rapidly thin out to an average of from 4 to 6 inches. A distinctive feature is the pronounced red-stained appearance of the beds on their exposed surfaces. A thin puddingstone-bed occurs near the base, and is made up largely of white quartz-pebbles. The chief peculiarity of the group as a whole is the regular alternation of grits and shales, and the parallelism of the upper and lower surfaces of the individual beds. Crinoid-rings are not uncommon in the grits themselves, and graptolites are met with in certain carbonaceous bands; but they are, at this particular locality, too badly preserved to admit of identification. At about 200 feet above the base of this division occurs a puddingstone-bed of considerable thickness, which forms a convenient horizon for separating this division from the succeeding one.

Gafallt Shales (Bb_2).—The cap of the hill is formed of a basin of pale grey and greenish-grey shales. Thin bands of sandstone or grit occurring throughout the group mark its affinity with the underlying division; but, considered as a whole, it is a shale-group as distinct from a series of grits. The harder bands are always felspathic, often ferruginous; and they generally decompose into soft rottenstones which rarely exceed 2 inches in depth. Another feature is the presence of worm-burrows preserved in orange-coloured limonite. The vertical thickness exposed is only about 50 feet.

(3) Exposures in Caban Côch Gorge.

As we leave the summit, and commence to descend into the Caban, we pass over the succession in descending order, repeated on the north side of the syncline. The individual beds in the gorge may be followed by the eye for some distance on both sides of the Elan as they sweep down towards the river itself; the Lower Conglomerate (Ba_1) can be traced eastward to the bed of the stream; but the upper divisions are truncated by a transverse fault passing through the west end of Cnwch Wood. The Intermediate Shales (Ba_2) appear to have a thickness of about 300 feet on the south side of the river, and the Upper Conglomerate (Ba_3) somewhere between 80 and 100 feet. Two quarries in the Lower Conglomerate (Ba_1) have been opened out, one on each side of the river. These are used for supplying building-material for the masonry-dams on the Elan works. The lowermost of these dams—the Caban Dam—is now being built, its foundations resting on the Lower Conglomerate. The excavations for the trench revealed a fine section in these beds, from which, with the addition of the two quarries, I have been enabled to form a very fair conception of the general characters of the greater part of this lowermost division. At the present time the faces of both quarries have been carried well back into the sides of the hills, and two exposures of clean rock are now to be seen. From an examination of these it may be concluded that the unweathered material is extremely tough, both in the grit and in the conglomerate, for the lines of fracture due to blasting pass through pebble and matrix alike, and it is practically impossible to remove a pebble from the matrix of the rock. A blow from a hammer produces little effect, and the forcible expressions employed by the masons while dressing the stone testify to its extreme toughness and resistance under the chisel. The individual beds reach 20 feet in thickness, and huge lenticular masses of pebbles occur throughout. Innumerable black clay-galls and patches of dark blue shale blotch the faces of the conglomeratic beds, many of them reaching a length of 12 or 18 inches. At about 50 feet below the top of the group is a thick zone of intermingled grits and thin slate-beds. Graptolites occur in the argillaceous bands, but they are few and far between, only *Monograptus crenularis* and *Climacograptus normalis* having been detected.

Many of the slates rapidly thin out and disappear, much in the same way as the pebble-beds; in fact, one gathers a general impression that the whole group is a collection of the material of successive shingle-banks which were deposited either close to the shore or in some river-estuary. The beds are much folded. In the dam-excavations they dip southward on the north side of the Elan; but in the quarry above they are seen to incline to the north. The total thickness of the Lower Conglomerate is estimated at over 200 feet in the Craig Cnwch crags to the westward.

The Intermediate Shales have a thickness of only about 250 feet above the northern quarry, or 50 feet less than on the opposite side of the river. It is therefore not improbable that a strike-fault passes along these beds, but no sign of it is apparent

The shales are well exposed under the Upper Conglomerate; but they are highly cleaved, and the extraction of fossils is a difficult matter. I have, however, identified *Monograptus lobiferus* and *Climacograptus normalis* from these rocks.

The Upper Conglomerate is exhibited from top to bottom, and from the road it is seen to be crumpled into numerous folds. Fragments of *Encrinites*, *Favosites*, and *Lindstrœmia* occur in certain bands, but they are difficult of removal, and uncertain of identification. The total thickness is about 90 feet.

Only 60 feet or so of the black-banded grits of the succeeding group is exposed along the line of section; and no sign of the puddingstone-bed has been detected at the top of the group. It appears to be cut out by a longitudinal strike-fault, which tilts the beds immediately above the cliffs into a vertical position. No fossils have been found in this neighbourhood; but, from the abundance of the species *Monograptus Sedgwickii*, Portl. in the same zone in other localities, I have ventured to give the name *Monograptus-Sedgwickii* Grits to this division (Bb_1).

From the fault to the Abernant stream, the sandstone-banded shales (Bb_2) are found to be greatly folded and no important thickness is exposed. At the stream itself the Abernant Fault brings down the Gwastaden Group (A) on the opposite side of the stream; and if the latter be followed down to its junction with the Elan it will be found that all the underlying divisions of the Caban Group terminate at the brook, or thereabouts. The grey-and-green shales are poorly shown in this area, being best exhibited on Corn Gafallt Hill, from which they derive their title.

The rocks on the north side of the Elan at Caban Côch all appear to have been subjected to much squeezing, for in hand-specimens and rock-slides alike the effect of movement is easily traceable. The proximity of the Abernant Fault possibly has something to do with this, for the nearer the beds approach to the dislocation the greater appears to have been the amount of crushing.

The Caban Group as developed at Caban Côch, we have now seen, consists of the following members:—

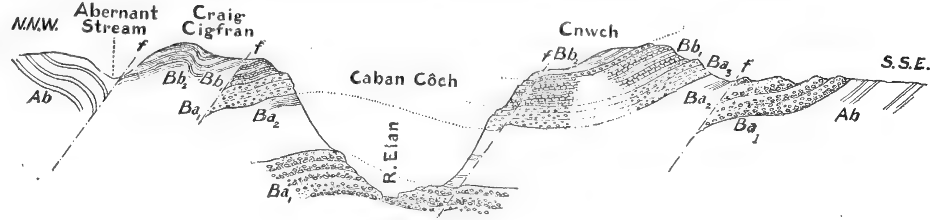
(1) A conglomerate-group at the base, made up of three divisions: (a) a lower conglomerate about 200 feet thick; (b) a mass of shales from 250 to 300 feet thick; and (c) an upper conglomerate about 90 feet thick.

(2) An upper group of two main divisions: (a) a series of alternating black-banded grits and pale grey shales, and (b) grit-banded and sandstone-banded grey shales.

The succession may be tabulated as follows:—

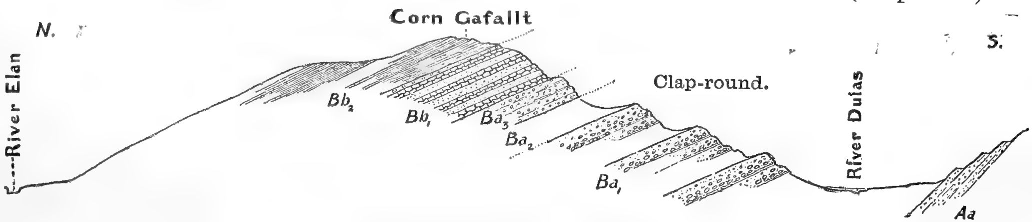
CABAN GROUP.	Gafallt Beds (Bb).	
		(Bb_2) Gafallt Shales.
		(Bb_1) *Monograptus-Sedgwickii* Grits.
	Caban Conglomerates (Ba).	
		(Ba_3) Upper Conglomerate.
		(Ba_2) Intermediate Shales.
		(Ba_1) Lower Conglomerate.

Fig. 10.—*Section across Caban Côch, from near Ty'n-y-graig to the Abernant.* (*See p. 100.*)



[Approximate length = $1\frac{1}{4}$ miles.]

Fig. 11.—*Section through Corn Gafallt Hill from the Dulas to the Elan.* (*See p. 105.*)



[Approximate length = $1\frac{1}{4}$ miles.]

B = Caban Group.	Ba = Caban Conglomerates.	A = Gwastaden Group.
Bb = Gafallt Beds.	Ba_3 = Upper Conglomerate.	Ab = Dyffryn Flags.
Bb_2 = Gafallt Shales.	Ba_2 = Intermediate Shales.	Aa = Cerig Gwynion Grits.
Bb_1 = *M.-Sedgwickii* Grits.	Ba_1 = Lower Conglomerate.	ff = Faults.

(b) *Confirmatory Sections through Corn Gafallt Hill.*

(1) Clap-round.

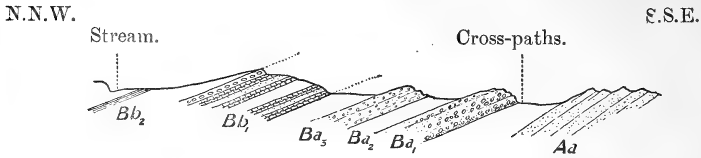
The accompanying section (fig. 11, p. 104) is taken through a spur on the south side of Corn Gafallt Hill at the eastern end of Erw Fawr Wood, and is continued up to and beyond the summit.

The Lower Conglomerate (Ba_1) is admirably exhibited in a series of fine scarps extending for a vertical height of about 300 feet up the hill, and dipping at about 20° north-north-westward. The beds show the same rotten felspathic matrix as that described on p. 100, in which are embedded large grit- and quartzite-pebbles, with smaller pebbles of white quartz, felsite, etc. The total thickness, as measured on the ground, is about 700 feet: at Caban Côch it is less than one-third of this amount. So sudden an increase in thickness, in a distance of $\frac{1}{2}$ mile, is difficult to account for: some proportion of it may be due to strike-faulting; but to prove this is no easy matter. Certainly no sign of such a dislocation can be discerned east or west of the section. Allowing, however, for the remote possibility that the whole of the beds are repeated, we should still have a thickness of 350 feet for the whole group, or 150 feet more than at Caban Côch.

A well-marked hollow and scarp at the summit of the lower group seems to indicate the place of the Intermediate Shales (Ba_2), but no exposures are visible. The estimated thickness is about 150 feet. The Upper Conglomerate (Ba_3), which succeeds the former, has increased in thickness to 150 feet. As a whole, the pebbles are much smaller than in the Lower Conglomerate, and consist mainly of white vein-quartz and grey grit.

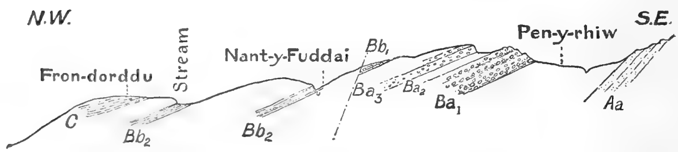
The Gafallt Beds (*Bb*) are now displayed to their best advantage, and fairly accurate measurements may be taken. The lower division (Bb_1) has a thickness of about 250 feet, of which the first 200 consists mainly of regularly alternating black-banded grits, and grey-and-green shales. The grit-surfaces of the beds, as before, are strikingly parallel, and the sinuous curves of many of the black bands, as seen on the joint-planes, suggest false bedding. The average thickness of the individual grits is from 4 to 6 inches, but this is exceeded in places at the base of the group. The indurated red weathering and the plentiful occurrence of crinoid-rings still form characteristic features. The uppermost 50 feet or so consists of a series of dark grey and white-striped grey flaggy shales, very much cleaved and contorted; and the whole group is capped by a bed of puddingstone, measuring at this point about 30 feet in thickness. This forms a very persistent band along the strike of the hill, and has proved exceedingly useful in the field for following out the run of the beds. The pebbles are chiefly of vein-quartz, and rarely exceed a cricket-ball in size; fragments of pale-blue slate are not uncommon. The matrix is very felspathic, for detached blocks of the rock weather into characteristically spheroidal boulders, the rock being recognizable at a glance. The decomposed rock has a honeycombed structure, as a result of the corrosion of the felspar.

Fig. 12.—*Section through Corn Gafallt Hill.* (*See p. 107.*)



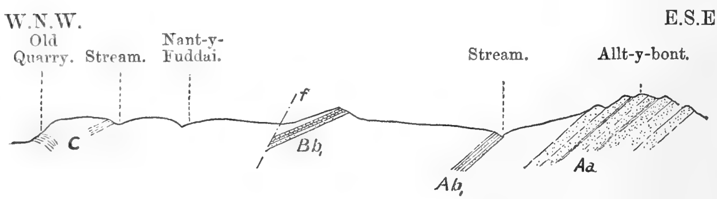
[Approximate length = $\frac{3}{4}$ mile.]

Fig. 13.—*Section from Pen-y-rhiw Cottage to Fron-dorddu Farm.* (*See p. 108.*)



[Approximate length = $1\frac{1}{8}$ miles.]

Fig. 14.—*Section above Dol-Ifor Farm, from Allt-y-bont to the old quarry.* (*See p. 109.*)



[Approximate length = $1\frac{1}{4}$ miles.]

C = Rhayader Pale Shales.
B = Caban Group.
Bb = Gafallt Beds.
Bb_2 = Gafallt Shales.
Bb_1 = *M.-Sedgwickii* Grits.
Ba = Caban Conglomerates.
Ba_3 = Upper Conglomerate.
Ba_2 = Intermediate Shales.
Ba_1 = Lower Conglomerate.
A = Gwastaden Group.
Ab_1 = Micaceous Flags and Grits.
Aa = Cerig Gwynion Grits.

The peculiar orange weathering of the grits, due to the presence of limonite, is still retained and forms a predominant feature.

Fossils may be found in one band about 100 yards south of the cairn. They are impressed as a rule into the grit-surfaces, and are in a fair state of preservation. The following species of graptolites were obtained:—

Monograptus Sedgwickii.
—— *spinigerus*, Nich.
—— *lobiferus.*
—— *harpago (?)* Törnq.
—— *involutus*, Lapw.
—— *Proteus*, var.
—— *Clingani*, Carr.
—— *decipiens (?)* Törnq.
Monograptus convolutus.
—— ——, var. *spiralis*, Gein.
Rastrites hybridus (?) Lapw.
Diplograptus sinuatus.
Dictyonema delicatulum, Lapw.
—— *corrugatellum*, Lapw.
Calyptograptus digitatus, Lapw.

And in addition to the crinoid-rings in the black-banded grits occurs *Favosites gothlandica*, Fougt.

The Gafallt Shales (Bb_2) which succeed the foregoing group have a thickness of at least 250 feet. They form the long dip-slope on the north side of the hill, and their maximum thickness may be measured with approximate accuracy. They consist of pale bluish-grey, greenish-grey, and green shales, and flaggy shales, all highly cleaved. They are striped with thin arenaceous bands which may be of hard grit or soft, rotten, brown or felspathic sandstone. They are monotonous in the extreme; for, with the exception of worm-markings, they are apparently barren of fossils. Their interest, however, lies in the fact that they form a transitional zone between the underlying rocks and the Rhayader Pale Shales (C).

(2) Corn Gafallt.

This section (fig. 12, p. 106) is taken about $\frac{3}{4}$ mile east of the preceding section. The Lower Conglomerate (Ba_1) has here a thickness of only 150 feet, and is separated from the Upper Conglomerate by a hollow, which answers to a vertical thickness of about 60 feet. This groove, we may assume, is the representative of the Intermediate Shales (Ba_2), but unfortunately no exposures are to be found. The hollow, however, is well marked, it may be traced both eastward and westward, and is found always separating the Upper and Lower Conglomerates. The Upper Conglomerate (Ba_3) is about 200 feet thick at this point, while 100 yards or so to the westward it reaches very nearly 250 feet. This sudden increase may be due possibly to faulting; but there is no means of proving this.

The *Monograptus-Sedgwickii* Grits (Bb_1) maintain a fairly constant thickness; but very few exposures of the Gafallt Shales (Bb_2) occur along the northern slope of the hill. Where beds are revealed, they are seen to dip at about 20° north-north-westward, the constant inclination of the whole series along this section.

As we pass eastward from the last section the beds gradually swing round to the northward. The puddingstone-bed, which can be easily followed, sweeps round at the end of the hill until it runs almost due north. It may be traced to a short distance above the

boundary-hedge, where it is cut out by a fault running from Llanfadog-Uchaf stream to Pen-y-rhiw Farm. The conglomerate-group is for the most part obscured with Drift, in the proximity of the dislocation. It is inferred, however, that it follows more or less parallel to the Gafallt Beds.

(3) Pen-y-rhiw.

The Lower Conglomerate (Ba_1) runs on continuously to Pen-y-rhiw Cottage, where it dips at about 20° north-westward. A section from the cottage to Fron-dorddu Farm (fig. 13, p. 106) practically follows the slope of the beds, and is useful for determining the succession at the eastern end of the hill. A deep hollow, equivalent to a vertical thickness of less than 50 feet, separates the two conglomerates, each of which measures approximately only 100 feet in thickness. At most, 50 feet of the Upper Conglomerate (Ba_3) is exposed; but this, as before, is readily recognized by its proportionately large number of white vein-quartz pebbles. The base of the Gafallt Beds (Bb) is signalized by an abrupt change in the gradient of the ground-surface; and at the uppermost gate on the path from Coppa Farm to Bwlch Côch Farm a small exposure of the *Monograptus-Sedgwickii* Grits (Bb_1) may be seen in the rill at the side of the lane, and in the lane itself, dipping at 26° north-westward. The grits are softer than their equivalents to the westward. They are more argillaceous, and attain an individual thickness of only 2 or 3 inches. The peculiar carbonaceous banding, however, leaves no doubt as to their exact horizon.

The rock is dark grey, and weathers externally to dark brown and metallic tints. The intercalated bluish-grey flags are evidently false-bedded, and are striped with thin wavy sandstone and rottenstone bands. A few of the black seams yield *Monograptus Clingani*, *M. lobiferus*, *Diplograptus Hughesii*, Nich., and *Climacograptus normalis*.

At a short distance below the gate a fault crosses the lane. This brings down the Gafallt Shales (Bb_2) which are exhibited in Nant-y-Fuddai to the westward, extending for 100 yards down the brook. West of this stream the ground is obscured by Drift, until the small barn south of Fron-dorddu is reached; and here the same sandstone-banded shales are again displayed dipping at 22° north-westward. In the lane to the farm, and in the farmyard itself, the first exposure of the Rhayader Pale Shales (C) is met with, these shales being faulted against the Gafallt Shales a few hundred yards to the south. They closely resemble the rocks of the underlying group, but the chief distinction lies in the total absence of arenaceous banding.

(4) Dol-Ifor.

Returning to the conglomerate-beds at Pen-y-rhiw, we may follow them as they swing round in a sharp curve to the northward. The Upper Conglomerate (Ba_3) ends at about 50 yards above the boundary-hedge, and the Lower Conglomerate (Ba_1) at the hedge itself, where it has a thickness of barely 50 feet. If the

hollow representing the base of the Gafallt Beds (*Bb*) be traced round from the preceding section it will be seen to have approached gradually nearer to the conglomerate-group, and at the line of the fence, where it is scarcely more than 50 yards from the base of the Lower Conglomerate, the two conglomerates appear to run up at an acute angle to the groove, and disappear at a short distance from it. Indeed this hedge forms the eastern limit of the conglomerate-group, for no sign of it can be detected to the eastward. A section taken between the fence and Dol-Ifor Farm shows only the Gafallt Beds (*Bb*) overlying the Gwastaden Group (*A*), and these poorly exhibited in a prominent rib immediately south of the farm (fig. 14, p. 106). The rock laid bare is a few feet only of hard blue slate, with white grit-bands, none of which exceed $\frac{1}{2}$ inch in thickness; in addition there are occasional seams of felspathic sandstone. The whole group is weathered to the peculiar red or orange colour of the *Monograptus-Sedgwickii* Grits (Bb_1). Graptolites may be found in certain bands, but they are, as a rule, badly preserved. I have, however, identified *Monograptus Sedgwickii*, *M.* sp., *Diplograptus Hughesii*, and *Climacograptus normalis*.

The Rhayader Pale Shales (*C*) are shown on the northern bank of the western brook, and in the quarry north of Fron-dorddu, where they dip south-eastward.

(c) *Additional Notes on the Caban Syncline.*

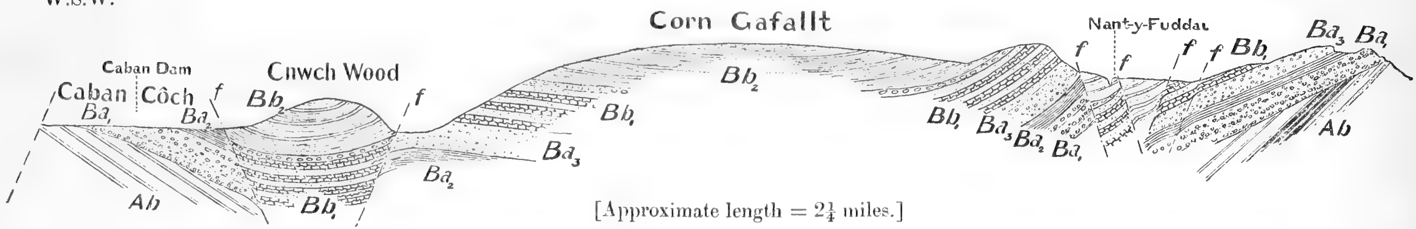
The preceding sections have been taken approximately in the direction of the dip. The typical section running nearly north-and-south, and the last roughly from east to west, would seem to indicate, in the change of dip, some folding in the Caban Group, when followed from west to east. If a section be produced from Caban Côch to Allt-y-bont it will cross at right angles nearly all the previous traverses, and show the structure of the Caban Group between its eastern and western limits (fig. 15, p. 110).

The typical section, though indicating the arrangement of the Caban Beds on both sides of the gorge, does not, at the gorge itself, follow the true dip, but runs more or less along the line of the strike. In the river-valley at Caban Côch and for nearly $\frac{1}{2}$ mile down the Elan, the true dip of the rock is north-westerly, and at an angle which may be anything from 10° to 40°.

Commencing our section east of the Abernant Fault, we come almost at once upon the Lower Conglomerate (Ba_1). In the river-bed itself it was well exposed, as already mentioned, in the Caban dam-foundations dipping north-eastward. This may be followed round the west side of Cnwch Hill, where it sweeps up in magnificent folds in the Craig Cnwch cliffs.

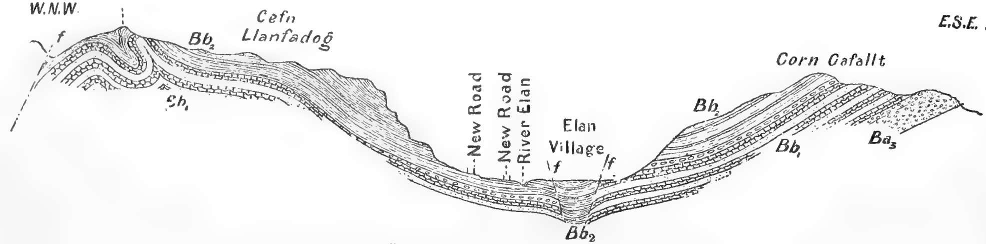
The overlying shales (Ba_2), which are not shown in the river-bed, are abruptly truncated by a cross-fault which brings down the Gafallt Shales (Bb_2) against them. This fault is intersected by two others, which bound the triangular mass of the Cnwch Wood spur, and thus the whole of the block may be regarded as a wedge dropped among its underlying beds by three boundary-faults.

Fig. 15.—*Section from Allt-y-bont Hill to Caban Côch.* (*See pp. 109, 111.*)



[Approximate length = $2\frac{1}{4}$ miles.]

Fig. 16.—*Section from Corn Gafallt to Careg Bica.* (*See p. 111.*)



[Approximate length = $1\frac{1}{2}$ miles.]

B = Caban Group.
Bb = Gafallt Beds.
Bb_2 = Gafallt Shales.
Bb_1 = *M.-Sedgwickii* Grits.
Ba = Caban Conglomerates.
Ba_3 = Upper Conglomerate.
Ba_2 = Intermediate Shales.
Ba_1 = Lower Conglomerate.
A = Gwastaden Group.
Ab = Dyffryn Flags.
ff = Faults.

The *Monograptus-Sedgwickii* Grits (Bb_1), which form a prominent outcrop on the north side of the river, should, by virtue of their dip, appear in an almost symmetrical form on the south. No exposures but those of the next higher division are to be found in this position; a fault, therefore, is required along the valley to separate the two groups. This, so far as I have been able to make out, runs at the foot of the sloping ground along the south side of the Elan. One end is apparently limited by the cross-fault already mentioned; the other by a north-easterly-and-south-westerly dislocation passing through Cnwch Farm. The shales crop out along the crest of Cnwch Wood and in the wood above the Elan Village Mission Hall. They are readily recognizable by their thin bandings of soft rotten felspathic and ferruginous grits, and the presence of worm-trails. Some of the seams appear to be calcareous, yielding casts of *Rhynchonella* and *Orthis* sp. *Monograptus Sedgwickii*, *M. lobiferus* (*Clingani*-type), and *M. Proteus* also occur. The dip is from 15° to 20° northward

Crossing the Cnwch Fault and ascending the eastern slopes of Corn Gafallt Hill, we enter ground that has already been described. The section, however, shows the gradual tilting-up of the beds as they are followed eastward, with the usual accompaniment of faulting, as they commence to swing round.

It is now evident that between Caban Côch and Allt-y-bont the rocks are folded into a gentle syncline, the true axis of which may be said to lie along a line from Cnwch Hill to Llanfadog-isaf. In order, therefore, to realize the maximum amount of folding that has taken place, a section should be shown at right angles to this axis. The typical section portrayed to some extent the western prolongation of the syncline in Cnwch Hill. A parallel line from Corn Gafallt Cairn to Careg Bica, about $\frac{3}{4}$ mile east, however, displays the fold to greater advantage (fig. 16, p. 110).

At Corn Gafallt Cairn the beds, as we have seen, dip north-north-eastward. These should, through their inclination, reappear on the north-western face of the hill in Allt Ddu wood. No exposures, unfortunately, are visible at this point; but, from the relief of the ground, it may be gathered that they run continuously from the cairn to the low ground. The nose of the faulted outlier is crossed by the section, but no rock is exhibited.

Once across the river, we are in new ground. The mass of Cefn Llanfadog rises almost precipitously before us, with terrace upon terrace up to the crest of the cliff, simulating an enormous thickness of rock. This is largely the effect of the impression that the beds are dipping northward, but it will be found on approaching the various outcrops that the dip is decidedly to the southward.

The *Monograptus-Sedgwickii* Grits (Bb_1) have been laid open in the cutting for the new road above the railway, and west of the outlet-end of the Foel Tunnel. For a study of this group in its unweathered condition it is one of the finest sections to be seen in the district. The beds are much crumpled and folded, and the true dip is often difficult to ascertain: it varies from 10° to 30° east-north-eastward and north-eastward.

Fossils may be extracted from certain carbonaceous seams within the grits. From a small exposure at the roadside about 50 yards west of the tunnel-mouth, the following have been obtained:—*Monograptus Sedgwickii*, *M. spinigerus*, *M. spiralis*, *M. Proteus*, *Diplograptus Hughesii*, *Retiolites perlatus*, Nich., *Dictyonema venustum* (?) Lapw., and *Climacograptus normalis*; and from beds about 800 feet inward from the end of the Foel Tunnel (Birmingham Aqueduct):—*Monograptus spinigerus*, *M. lobiferus*, *M.* sp. with a *tenuis*-like curve, *Dictyonema delicatulum*, and *Retiolites perlatus*.

This *M.-Sedgwickii* Group does not cross the line of section, but it is convenient to note the exposure at this stage. The actual traverse passes 100 yards or so east of the point where the uppermost beds of the grit-group meet the river. The puddingstone-bed has not been detected at this locality: it is possible that it is merely of local occurrence, and thins out to the northward.

Returning to the section, we find ourselves in the Gafallt Shales (Bb_2) immediately above the new road. The beds dip at variable angles southward and south-eastward below the crest; above the crest they seem to be very greatly folded, and even inverted. I attempted to subdivide the Gafallt Shales and to work out the structure of the hill in detail; but so folded are the rocks, and so similar throughout, that the idea was at last abandoned as impossible. Two facts, however, are certain: the general dip of the beds to the south and south-east, and the great sag of the Caban Group in the river-valley. The reappearance of a small patch of the *M.-Sedgwickii* Grit at Careg Bica Cairn, on the north side of the syncline, completes the proof of our general results. Only a few thin black-banded grits are seen *in situ* at the cairn itself; but they are distinctive and easily recognizable as belonging to the lower grit-division. The small exposure of rock shows intense folding and inversion.

The whole of the high ground of Cefn Llanfadog Hill is, from Abernant stream to Llanfadog-Uchaf, occupied by these southward-dipping Gafallt Shales, and at Llanfadog-Uchaf a well-marked fault brings down the Rhayader Pale Shales (*C*) against them. This fault is traceable from Llyn-clap, through the stream-hollow at Llanfadog-Uchaf, on to Pen-y-rhiw Farm, where it appears to die out. The abrupt termination of the puddingstone-bed south of Fron-dorddu is probably due to a branch of the same fault.

(d) *Discussion and Summary.*

Before discussing the possible explanations of the various phenomena which have been presented to us during our examination of this Caban Group, it may be as well to recapitulate the general results that have been obtained. The Caban Group consists of two main members—a lower group of two massive conglomerates separated by a series of shales; and an upper group, with grits at its base, passing up into pale grey flags and shales. The whole group occupies the huge syncline, the axis of which runs from north-north-

east to south-south-west. The two conglomerates are thickest in the centre of the area occupied by their outcrops, and thin out when followed both eastward and westward; while the Intermediate Shales (Ba_2) become greatly attenuated when traced eastward. Moreover, not only is the conglomerate-group lenticular as a whole, but we have seen, in the Caban Quarries, that its individual beds also are lenticular in form. Again, the conglomerates at the eastern limit disappear under the overlying *Monograptus-Sedgwickii* Grits, which, in turn, with the Gafallt Shales, vanish beneath the Rhayader Pale Shales east of the Elan, for having once crossed the river we find no trace of these divisions, the Caban Group having wholly disappeared under the Rhayader Group. The remarkable appearance of this huge wedge of the Caban Group between the Rhayader and Gwastaden Groups surely demands an explanation. Three interpretations may be suggested :—(1) faulting, (2) overlap, and (3) faulting and overlap in combination. Let us examine each of these in turn.

(1) Faulting.—This would require in its simplest form a thrust-fault at the base of the Lower Conglomerate, from Caban Côch to Pen-y-rhiw, passing thence gradually up the line of separation between the Caban and the Gwastaden Groups, until the base of the Rhayader Pale Shales is met with somewhere about Glan Elan. As, however, the line of strike of the Rhayader Pale Shales is uninterrupted on either side of the river, another fault at the base of the Rhayader Group would be necessary. Now, a thrust-fault in its primary form is a level or inclined plane, more or less flat and undeformed. But if the plane at the base of the Caban Series were developed, it would be found to be extremely irregular, pitching and rolling in all directions. It may be argued that, assuming the existence of a thrust-plane, it has been folded and crumpled since the original thrusting had taken place. Such a suggestion, however, is inadmissible; for one would expect a corresponding series of folds in the outcrop of the Cerig Gwynion Grits lying immediately to the south, and no such folds are to be found in these rocks: their outcrop is even and regular along the line of strike. Again, with the exception of the Caban area at the extreme western limit of the outcrop, no signs of great movements are exhibited in the Caban rocks themselves at all compatible with the results to be expected from so great an overthrust. The conglomerates on Corn Gafallt Hill run regularly and smoothly, with no signs of folding and thrusting; and, except in the neighbourhood of small faults, the beds appear undisturbed. Finally, we have seen that in the basement-beds at Ty'n-y-graig the conglomerates contain fragments of the shales that underlie them in the immediate vicinity. Even admitting, then, the existence of a thrust-fault, it is evident that the Caban Series could not have been pushed forward the distance necessary for so huge a lenticle to shove itself between the Rhayader and the Gwastaden Groups.

(2) Overlap.—'Overlap occurs in a conformable series when each succeeding bed stretches beyond the limits of that below it in one or more directions, so as to have a wider extension, and to conceal the edges of the lower beds . . . . . Overlap is indeed a necessary consequence of the underlying surface of denudation being an inclined plane instead of a horizontal one, consequently any slope in an area of subsidence will give rise to the phenomena of overlap.'[1] In brief, overlap involves:—(i) A sloping surface on the older area of denudation. (ii) The natural thinning-out of the individual beds of the overlying series before they are overlapped. (iii) Subsidence in the area of deposition. (iv) Unconformability between the two groups: this follows of necessity. (v) An extension of each succeeding bed wider than that of the underlying one.

Let us examine the Caban Group and see how these conditions apply. We have already noticed that the conglomerates thin out eastward and westward, and that they are at their thickest in the central area. The reason of this is simple, in view of the fact that the greatest amount of denudation of the Gwastaden Group has taken place in the central portion of the western area, where the conglomerates rest nearly on the Cerig Gwynion Grits; while at the eastern and western limits they repose on beds between 100 and 200 feet higher up in the group. That is to say, we have phenomena satisfying condition (ii). The wider extension of the beds has been demonstrated; for the *Monograptus-Sedgwickii* Grits extend farther eastward than the conglomerates; they reach, in fact, beyond the point where the conglomerates disappear. The overlying Gafallt Shales again, would, if produced under the river-alluvium, extend to Glan Elan, about 500 yards still farther east, while the Rhayader Pale Shales may be carried on for at least 4 or 5 miles beyond the point at which the whole of the Caban Group has vanished. Of condition (v) we have already had proof.

So much, then, for the general facts which go to prove overlap. If, however, further proof be required in detail, it may be obtained in the high ground between Pen-y-rhiw, Coppa, and Dol-Ifor Farms. If this area be carefully mapped on a large scale, it will be found that each successive ridge or hollow, representing some division of the Gafallt Group, will gradually approach the edge of its underlying bed, pass over it, and be eventually covered up by the next higher division. The base of the Gafallt Group (Bb_1) may be easily traced over the Upper Conglomerates (Ba_3). This line of separation takes the form of a distinct groove sweeping over the hill in a sharp curve, which no fault could possibly produce. It approaches the conglomerates by degrees, and, at the boundary-hedge, apparently passes over their edges, ultimately coming to rest on the underlying Gwastaden rocks. Another ridge, at the foot of the wood above Coppa Farm, may be traced without

[1] A. J. Jukes-Browne, 'Students' Handbook of Physical Geology' 1884, p. 384.

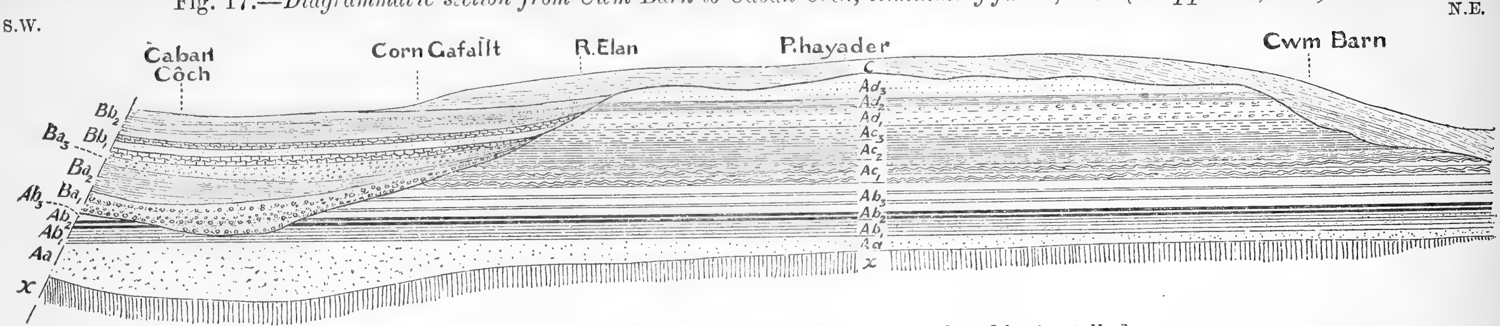
difficulty to the edge of the last division and over it, and in the same manner as the basement-bed will eventually be found reposing on the Dyffryn Flags at Dol-Ifor Farm. Unfortunately little rock is exposed, but the relief of the ground so persistently bears out the suggestion of overlap that a survey of the area renders the true condition of affairs absolutely conclusive.

(3) Faulting and overlap in combination.—This may be dismissed; for, if once overlap be conceded, it is unnecessary to complicate the problem by the addition of thrust-faulting.

What, then, must have been the physical conditions at the time of deposition of the Rhayader and Caban Groups necessary to bring about these remarkable phenomena? In the first place, it is evident that this Caban Group was deposited subsequent to the Gwastaden Group, and before the Rhayader Pale Shales; for we have seen that it is overlain by the Rhayader Group, and underlain by the Dyffryn Flags of the Gwastaden Group. Consequently it occupies a position somewhere between the Dyffryn Flags and the Rhayader Group. It cannot rest between the Dyffryn Flags and the uppermost beds of the Gwastaden Group, for I have proved that there is no such break in the succession of the higher Gwastaden sediments as might represent the time of the deposition of the Caban rocks. The succession is consistent, and has been checked from point to point, in order to show the conformable relationships of the various divisions throughout. The only sign of irregularity is between the Gigrin Mudstones and the Rhayader Pale Shales. Nor can this Caban Group be a representative of any one of the Gwastaden divisions, for its graptolites are not comparable with those of the Wye Valley. The Gafallt Grits, it is true, yield several of the species common to the uppermost beds of the Gwastaden Group, but with many new forms in addition. One would suppose, therefore, from palæontological evidence alone, that in the Caban area a set of beds younger than those of the Gwastaden Group occurs. The Caban rocks, being newer than those of the Gwastaden Series, and being overlain by the Rhayader Pale Shales, must occupy, then, a position between these two groups.

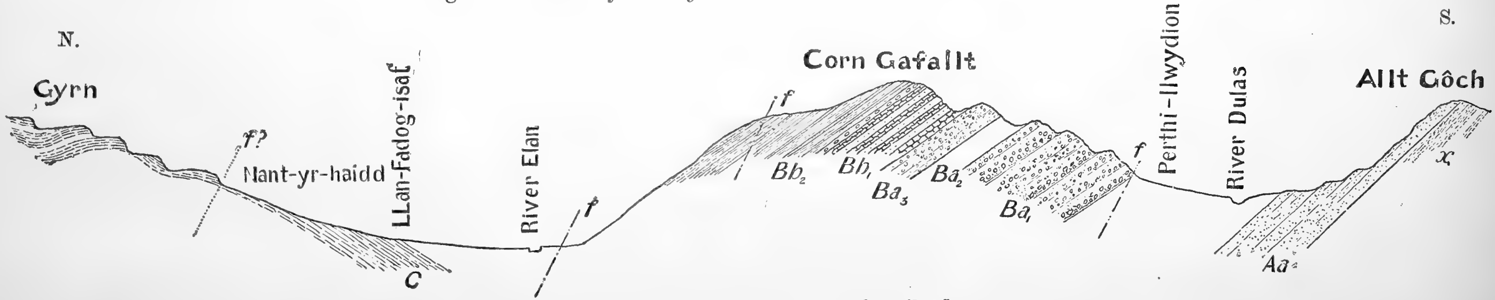
Having now shown that the Caban Group represents the great break between the Gwastaden and the Rhayader Groups, and bearing in mind the overlaps that occur within these upper groups, it becomes an easy matter to trace the ancient history of the rocks. The simplest method, perhaps, of showing the relationship of the various groups is by means of a longitudinal section taken along the base of the Rhayader Pale Shales, restoring the ancient land-surface to its original form by eliminating all faults crossed by the section (fig. 17, p. 116). At the western end of the district the Pale Shales rest immediately on the zone of *Monograptus tenuis*, and proceeding eastward a greater thickness of the Gwastaden Group becomes visible, until, at the Tannery, its

Fig. 17.—*Diagrammatic section from Cwm Barn to Caban Côch, eliminating faults, etc.* (*See pp. 115, 117.*)



[Approximate length of section=7 miles. Gwastaden Beds plotted horizontally.]

Fig. 18.—*Section from Gyrn Hill to Allt Gôch.* (*See p. 119.*)



[Approximate length of section=$2\frac{1}{2}$ miles.]

C=Rhayader Pale Shales.

CABAN GROUP.
- Bb_2=Gafallt Shales.
- Bb_1=*M.-Sedgwickii* Grits.
- Ba_3=Upper Conglomerate.
- Ba_2=Intermediate Shales.
- Ba_1=Lower Conglomerate.

GWASTADEN GROUP.
- Ad_3=Pale Grey Mudstones.
- Ad_2=Zone of *M. convolutus.*
- Ad_1=Calcareous-Nodule Beds.
- Ac_3=Zone of *M. fimbriatus.*
- Ac_2=Zone of *M. cyphus.*
- Ac_1=Zone of *M. tenuis.*

GWASTADEN GROUP.
- Ab_3=*D.-modestus* Beds.
- Ab_2=Rottenstone Beds.
- Ab_1=Micaceous Flags and Grits.
- Aa=Cerig Gwynion Grits.

x=Blue-black Shales.
ff=Faults.

maximum thickness is exposed beneath the overlying group. In the section the beds of the Gwastaden Series are taken as horizontal, and all overlying rocks are plotted from off this datum. At Glan Elan Farm the Gafallt Shales would begin to peep out beneath the Rhayader Group, were it possible to remove the river-alluvium from the underlying rock. A little farther west the *Monograptus-Sedgwickii* Grits appear beneath the shales, and still farther west the conglomerates beneath the grits. We have, in fact, in the vertical section, the same set of conditions as those that exist along the line separating the two groups in the field. The lower down we go into the Gwastaden Group, the lower are the rocks that make their appearance in the Caban Group. The beds are shown thinning out and overlapping one another, as on the ground.

A study of this section enables us to infer the various stages in the history of the period in which these rocks were deposited, and at the same time furnishes us with a clear conception of the meaning of the various overlaps that have taken place. It is probable that at the close of the period of deposition of the Gwastaden rocks the sea-floor was elevated into dry land. During this elevatory period the newly-deposited rocks were denuded to a surface represented by the outline shown in fig. 17 (p. 116). The least amount of denudation occurred in the area now occupied by the Wye Valley; east and west of that area more material was removed. To the west of the Elan a great hollow was worn out, the land-surface sloping rapidly away from Glan Elan towards Caban Côch. Subsidence of the land now commenced, and into the eroded hollow the sea gradually encroached, laying down the beds of the Lower Conglomerate (Ba_1). It is possible, and even probable, that these beds were deposited in the estuary of a river, which we may assume was responsible during the 'dry-land period' for the scouring-out of the hollow.

As subsidence went on the sea extended farther inland, so that in Gafallt times the sea-waters were laying sand and mud not only upon the Caban sediment, but upon the old surfaces which were dry land while the conglomerates were being laid down. In this way the disappearance of the conglomerate-group in certain areas is easily accounted for.

At the close of Gafallt times and at the beginning of the period of the deposition of the Rhayader Group, we may conclude that the old hollow was filled up by the previous deposits, so that the sea had now an almost flat floor over which to extend as subsidence went on. A sinking of a very small amount consequently would mean a rapid inland progression of the sea-line. It would therefore seem to follow that after a comparatively short epoch the shore lay probably several miles to the eastward, bounding some broad sea in whose quieter waters the pale shales and mudstones of the Rhayader Group were laid down.

Such, then, appears to be the history recorded by these rocks. How far westward the old hollow extended is at present a mystery.

The attenuation of the conglomerates in the western areas, and the gradual lessening of the amount of denudation of the Gwastaden rocks indicate an ancient land-surface sloping from west to east, and facing the western side of the old hollow already described; it is not improbable, therefore, that in the absence of the unfortunate Abernant Fault we should find no great extension of at least the lower portions of the Caban Group, were we able to follow them to the westward. Their appearance on a map would most likely be that of a huge lenticle dying out eastward and westward beneath the Rhayader Group, and somewhat resembling a hand thrust from beneath a blanket.

An interesting question that is likely to be raised is the derivation of the materials of the Caban Conglomerates. The large grit- and slate-pebbles seem to be of Gwastaden age, and their size points to the fact that they cannot have travelled from any great distance. It appears, therefore, most probable that, being of local occurrence, they were derived from the bordering cliffs of the old Caban coast, from which fragments dropped into the shallow water of the sea, forming banks of shingle, the pebbles of which successive tides rolled into their present rounded forms.

The finer fragments of igneous rock—felsites and the like—are more difficult to account for. The nearest masses of igneous rock occur in the Carneddau and Llanwrtyd hills on the south. It is therefore just possible that these rocks in the localities mentioned furnished many of the felsites in the Caban Conglomerates, and are at the same time responsible for the felspathic fragments of the matrix. The confirmation of this suggestion, however, awaits more extended investigation, and until such is made the matter must remain uncertain.

One word more before we leave this most interesting Caban Group. Is it not possible that the synclinal form of the Caban Series is partly the result of the deposition of the beds on steeply-sloping shores? To prove this would be difficult. The base of the Rhayader Group runs nearly parallel to the strike of the Gwastaden rocks, and it seems only natural to suppose that once the Caban rocks were laid down the old Gwastaden conditions were resumed. On the other hand, the syncline is carried well into the Pale Shales between Coed-y-mynach and Llanfadog-Uchaf. Much of the folding, therefore, appears to have taken place after the Pale Shale period.

Finally, we notice that the Cerig Gwynion Grits and the Caban Conglomerates attain their greatest thickness in the approximate axis of the Caban syncline, and it is therefore not improbable that the syncline is more or less a tectonic structure throughout, which commenced in Gwastaden times, was continued through Caban times, and had not come to rest until long after the deposition of the Rhayader Pale Shales.

(C) The Rhayader Pale Shales.

This great group of pale shales and mudstone is by far the most complicated and perplexing of the entire succession. So monotonous in lithological characters, so devoid of fossils, and in addition so highly cleaved are the rocks, that they offer little inducement to the geologist to unravel the stratigraphy of the great area over which they are spread. They closely resemble the underlying Gafallt Shales, and it was some considerable time before I could find any means of distinguishing between them. If the line of strike of the base of the Rhayader Group be carried west of the Elan it will be found to follow the small rill immediately east of Fron-dorddu Farm. In the steep slope on the west side of the brook, patches of the Rhayader Group occur at the bottom of Coed Bwla, and on the east side of the brook the Gafallt Shales make their appearance in the neighbourhood of Fron-dorddu. It was in this particular locality that I found a clue which proved of use to me in separating out the two groups. The only means of detection lies in the fact that the Gafallt Shales are always striped with thin arenaceous bands, while the shales of the Rhayader Group show little or no sign of such banding. This may seem a slender basis on which to work. It seems but reasonable, however, to suppose that if this distinction exists at the point where the two groups are seen together, it will exist for a mile to the westward, and it is only within this mile that the difficulty of separation occurs; for at the end of that distance we are at the western limit of the area under examination. By the above method the fault from Llyn Clap to Pen-y-rhiw was detected. This has already been mentioned as bringing down the Rhayader Shales against the Gafallt Group. It is doubtful whether this fault has much downthrow: this can be proved only by extended investigations. It may be that there is a gradual passage up from the one series to the other; but, so far as I have been able to make out, the line of separation between the two lies along this fault, or thereabouts.

The shales in the low-lying parts of the valley between Coed-y-mynach and Llanfadog-Uchaf all dip in a south-easterly direction in correspondence with the syncline produced from Caban Côch. On reaching the higher ground to the northward, however, great folding and inversion apparently begin to take place.

Fig. 18 (p. 116) is a section from Gyrn Hill to Allt Gôch, in a north-to-south line. This shows the three main groups, namely, the Gwastaden, Caban, and Rhayader. In order that their relationship may be thoroughly understood, the old ground need not be described again. The Rhayader Pale Shales are well exhibited in Nant-yr-haidd and in the scarp of Gyrn Hill. They present throughout the same uniform type of rather soft, pale grey, blue, and green flags and mudstones. Some of the beds are striped with white and blue seams, a few of which yield fairly well-preserved

fossils. They are, however, highly cleaved; fragments only of graptolites may be extracted, and these with difficulty. From a few blue bands about 100 yards above the lane the following forms have been obtained:—*Monograptus turriculatus*, Barr., *M. Becki*, Barr., *M. Sedgwickii*-type, *M. jaculum*, Lapw. and *Rastrites distans*, Lapw. Orange-coloured worm-trails are of frequent occurrence throughout the group. The general dip is from 10° to 15° downstream.

As we leave the brook and ascend the steeps of the Gyrn escarpment, the rock is seen to become more highly cleaved, and of shaly rather than a mudstone type. At the same time a variable dip sets in, and at the summit folding and even inversion seems to have taken place. Graptolites are rare, and can only be seen on the sharp edges of the shales. One orange-weathering band about halfway up the slope contains *Monograptus lobiferus*, *M. Becki*-type, *M. runcinatus*, Lapw. and *M. jaculum*.

Excellent exposures of these pale shales are visible in the new road-diversions at Llanfadog-Isaf, in the sides of the railway-cutting, and in the banks of the Elan close to the small footbridge at Coed-y-mynach. They are crammed, as a rule, with orange-coloured worm-markings, and dip uniformly at from 10° to 15° southward and south-eastward. From the new road-cuttings I have extracted *Monograptus runcinatus* and *M. Becki*.

A very fossiliferous set of rocks at the base of the Rhayader Group has been opened out in the side of the Cambrian Railway-cuttings, a short distance north of the level crossing at Glan Elan. The rock is a pale bluish-grey mudstone. Seams of orange limonite yield graptolites, preserved in the same material. These include *Monograptus Sedgwickii*, *M. crassus*, Lapw., *M. lobiferus* var. *undulatus*, Perner, and *Petalograptus palmeus* var. *tenuis*, Barr. Farther north along the line, on either side of the tunnel, the cuttings have exposed fine sections of these shales. They are, however, barren of fossils.

In the Wye Valley, at the bend south of St. Winifred's Church, a series of purple mudstones, intermingled with pale green mudstones, come in. Their chief interest consists in their purely local occurrence. The cuttings for the Birmingham Aqueduct exhibited a complete section of these bands in the sides of the trench, but in no other locality does there appear to be the least sign of this remarkable set of purple rocks. It is to be regretted, for they form bands so distinct that the process of following them out in the field would have been simple, and at the same time would have enabled us to form some idea of the structure of these basement-beds.

The junction of the Rhayader and Gwastaden Groups was not revealed in the trench, the rocks being covered by a thick mass of Drift. This again was especially unfortunate, for it would have been very interesting to have actually seen the one group resting unconformably upon the other.

About ½ mile east of Rhayader, in the banks of Rhyd-hîr Brook, a section of a somewhat higher set of shales is visible. The rock is intensely cleaved: with patient industry, however, fragments of a few graptolites of the following species may be collected:—*Monograptus Sedgwickii* var. *distans* (?), *M. intermedius*, Carr. *M. crassus*, and *Climacograptus extremus*. These forms appear to belong to the same horizon as that of the Tannery and the Glan Elan beds. Farther east several new species appear. One very fair exposure occurs in the Rhyd-hîr east of Beili-newadd. The lower beds are of the ordinary pale shale-and-mudstone type; but higher up the group, in the plantations east of the farm, a set of false-bedded, impure, micaceous grits make their appearance. These are banded with thin carbonaceous seams yielding poorly-preserved examples of *Monograptus priodon*, Bronn. If a collection of graptolites, however, is desired, one cannot do better than visit the small stream west of Llwyn-y-Baedd. In the brook west of the quarry, many of the exposed shales are crammed with well-preserved examples of *Monograptus priodon* and *M. exiguus*, Nich.

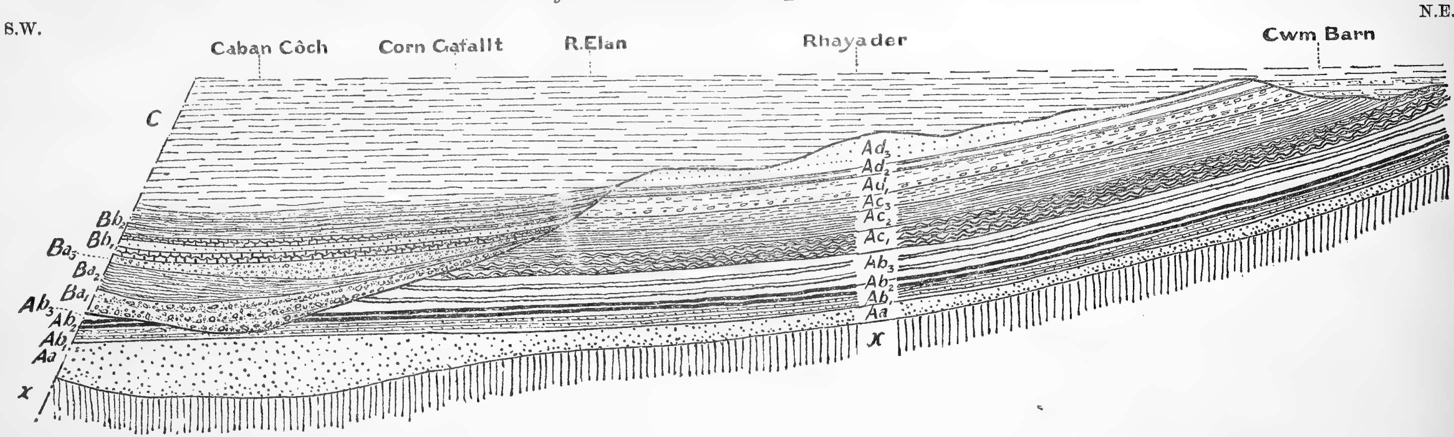
At Cwm Barn, about ½ mile farther east, the base of the Rhayader Series is made up of intermingled grits and shales. The appearance of this new set of conditions is perhaps rather startling at first sight; and I was at one time inclined to believe that the Gafallt Group had once more appeared between the Rhayader and Gwastaden Groups. But the included fossils prove conclusively that these arenaceous rocks are merely a local development of the Rhayader beds which we have been studying. The lower division consists of alternating pale grey calcareous shales and impure grits, with occasional thin seams of limestone. The shales weather to a characteristic dark brown. Opposite the old quarry, and in the old quarry itself, thin beds of soft rotten conglomerate are exhibited. These are highly fossiliferous, and yield the forms enumerated in the following list:—

Atrypa reticularis, Linn.
—— *imbricata*, Sow.
Leptæna rhomboidalis.
—— *sericea (?)* Sow.
—— *transversalis.*
Meristella sp.
Orthis calligramma, Dalm.
Orthis elegantula.
Pentamerus sp.
Spirifer sp.
Strophomena pecten (?).
Favosites gothlandica, Fougt.
—— (*Stenopora*) *fibrosa*, Goldf.
Petraia bina, Lonsd.

In addition to the foregoing I have detected *Monograptus Sedgwickii* var. The dip is about 28° north-westward.

Above the quarry the grits become rather thicker, attaining a thickness of 3 or 4 inches. They are black-banded, as a rule, yielding *Monograptus priodon* and *M. Sedgwickii* var. The total thickness of this grit-series up to the first hedge is about 150 feet. Beyond this point the grits commence to thin out, and pass up into pale blue-and-grey shales, barren of fossils. About 500 yards above Cwm Barn the rocks are obscured by Drift, and no further sections are revealed.

Fig. 19.—*Diagrammatic section from Cwm Barn to Caban Côch, showing the relationships of the rocks of the Caban and Rhayader Groups to those of the Gwastaden Group.* (*See p. 123.*)



[Approximate length of section = 7 miles. Rhayader Pale Shales plotted horizontally.]

C = Rhayader Pale Shales.

CABAN GROUP.
- Bb_2 = Gafallt Shales.
- Bb_1 = *M.-Sedgwickii* Grits.
- Ba_3 = Upper Conglomerate.
- Ba_2 = Intermediate Shales.
- Ba_1 = Lower Conglomerate.

GWASTADEN GROUP.
- Ad_3 = Pale Grey Mudstones.
- Ad_2 = Zone of *M. convolutus*.
- Ad_1 = Calcareous-Nodule Beds.
- Ac_3 = Zone of *M. fimbriatus*.
- Ac_2 = Zone of *M. cyphus*.
- Ac_1 = Zone of *M. tenuis*.

GWASTADEN GROUP.
- Ab_3 = *D.-modestus* Beds.
- Ab_2 = Rottenstone Beds.
- Ab_1 = Micaceous Flags and Grits.
- *Aa* = Cerig Gwynion Grits.

x = Blue-black Shales.

The most easterly exposure that I propose to examine on the fringe of these pale shales lies about a mile north-east of Cwm Barn. It may be reached by following the road to Abey-Cwmhir up the Drift-covered valley of the Dulas. One or two small sections may be noticed on the hillsides, and in the stream to the north of Cwm-gwr, but the above-mentioned exposure offers more interest. It may be found in a small quarry on the east side of the Bwlch-sarnau road, about 500 yards above the bridge. The rocks are mainly soft, pale grey shales, interbanded with grits, and weathering to a brilliant orange colour. The shales are quite free from cleavage, and graptolites, which are abundant in certain seams, may be readily identified. They are well preserved, and consist of the following species:—

Monograptus priodon.
—— *Holmi,* Perner.
—— *Marri (?)* Perner.
—— *Sedgwickii.*
Monograptus galaensis, Lapw.
—— *nudus,* Lapw.
—— *runcinatus.*
Retiolites obesus, Lapw.

The beds seem to be folded on both sides of the valley. On the west side the dip is north-westerly, while in the above quarry the beds pitch at 55° east-south-eastward.

This, then, completes our examination of the southern border of the Rhayader Group. One remarkable peculiarity may be noticed—the manner in which the fossil species die out from west to east, giving place to new forms. From this it will be inferred that in following the Rhayader fringe we are not tracing the same bed or horizon, but ascending the series. A fault separating the Gwastaden and Rhayader Groups might explain this, but the basal line of the pale shales is not of the form that usually results from a dislocation—it is too irregular and undulating. It seems, therefore, natural to infer, along this line, the same set of conditions as that which we have seen prevail at the base of the Caban Group; that is, an ascent in the group when the line of junction between it and the underlying series is followed from west to east,—the direct result of overlap produced by a sinking of the sea-floor during deposition. It seems also more than likely, that, in order to produce this particular overlap, the denuded Gwastaden surface was slightly tilted up to the eastward, as shown in fig. 19 (p. 122). This is practically the same section as that figured on p. 116 (fig. 17). The Rhayader Pale Shales, however, are plotted in an horizontal position, to reproduce the sea-floor conditions of Rhayader times. An arbitrary thickness of rock between the Llanfadog and Cwm Barn beds is assumed. It would seem, then, in order to bring about the existing conditions, that the Gwastaden beds were elevated to the eastward, previous to the deposition of the Rhayader Pale Shales. The vertical heights in the section are greatly exaggerated: in consequence of which the easterly tilt appears very much greater than is likely to be the case. The real amount of elevation is

probably so slight that it would be scarcely visible on a natural-scale section.

No attempt has been made to lay down more than the southern edge of this series of Pale Shales. They cover an immense area of ground; for they may be traced nearly to the Severn Arms, some 5 miles north-west of the town of Rhayader, and 10 miles north-eastward to Bwlch-sarnau, where they join the Tarannon Shales, indicated on the Geological Survey map.

Two other localities for fossils may be mentioned. The first, an old quarry on the road to St. Harmons about 300 yards north of Pen-y-bwlch, yields *Monograptus exiguus*, *M. nodifer*, Törnq., *M. nudus*, *M. jaculum*, *M. discus*, Törnq. and *M. spiralis*, Gein. The second, in the lane-side at the ford across Nant Serth, 300 yards south-east of Middle Nant Serth Farm, has yielded *Monograptus exiguus*, *M. crispus (?)* Lapw., *M. nudus*, *M. discus*, *M. priodon*, and *M. galaensis (?)* Lapw.

In concluding this part of our survey it will be of interest to examine the palæontological results, and to observe how they bear out those which have been deduced from stratigraphical evidence alone. If we refer to the list of fossils recorded from the topmost beds of the Gwastaden Group, we find that out of the species enumerated, only one—*Monograptus lobiferus*—passes up into the Rhayader Group. What has become, then, of the remaining forms? The list of the Caban fossils contains at least four of these, namely:—*Monograptus convolutus*, *M. crenularis*, *Diplograptus sinuatus*, and *Climacograptus normalis*, besides *M. lobiferus*, which is common to all three groups. Again, these Caban rocks yield *M. Sedgwickii* and *M. involutus*—species occurring in the Rhayader Pale Shales but not in the Gwastaden Group. The Caban beds, therefore, occupy a position intermediate between the Gwastaden and Rhayader Groups. This is in perfect accord with the inferences already drawn from stratigraphical results alone.

III. General Summary.

(*a*) The Rhayader Sequence.

We are now in a position to summarize the collective results which have been obtained from our examination of the Rhayader district as a whole. We have seen that no one section taken in any direction across the country shows a complete succession from bottom to top. In any area or sub-area that we may choose to consider, one group of rocks is always better developed than another, and some portion at least of one group is certain to be missing. Little is it to be wondered, then, that the geology of the district from a stratigraphical aspect has presented problems of some complexity. From the evidence that has now been secured, however, the true sequence of the various groups is placed beyond question. The detailed stratigraphy alone would be sufficient; but, in addition,

such a wealth of palæontological evidence has been collected that the various components brought together in proof of the order of succession are now finally welded into a rigid and inflexible whole.

The Rhayader Valley, as I have shown, is floored by rocks belonging to three great groups—the Gwastaden, the Caban, and the Rhayader. The lowest of these, the Gwastaden Group, has a maximum thickness of over 1800 feet. It is underlain, with apparent conformity, by a mass of highly-cleaved Dark-blue Shales; and is overlain unconformably by both the Caban and Rhayader Groups. The base of the Gwastaden Series is formed of a thick mass of grits or greywackes, which thin out eastward and thicken out westward. They contain graptolites of the genus *Climacograptus* only, and pass up gradually into a series of flags and grits, which yield both Climacograptidæ and Diplograptidæ. These are succeeded by a thick group of shales and mudstones—the Ddôl Shales and Gigrin Mudstones—where the first Monograptidæ make their appearance: the variations in the forms of *Monograptus* rapidly increase towards the summit of the group, where this genus becomes predominant.

The Caban Group which overlies the Gwastaden rocks has a maximum thickness of 1500 feet. It is found only in the western areas, between the Gwastaden and Rhayader Groups. Its lowermost division—the Caban Conglomerates—is made up of two massive lenticular conglomerates, with an intermediate set of shales. The conglomerate-group passes up into a set of fine-grained grits, the *Monograptus-Sedgwickii* Grits, and finally into the shales and flags of the Gafallt Shale division. Each of the various divisions throughout the whole of the Caban Group, when followed eastward, is found to be overlapped or covered up by the next higher bed, so that eventually the whole of the Caban Group completely disappears beneath the overlying Rhayader Pale Shales.

The Rhayader Pale Shale Group is made up of pale green, blue, and grey shales and mudstones. It overlaps the Caban Group, but not necessarily unconformably. East of the point of complete overlap, these Pale Shales rest irregularly upon the Gwastaden Group, lying on lower and lower rocks of the group, as we pass eastward; and it is not unlikely that, if traced farther eastward out of the Rhayader district, they would be found to have completely covered over the whole of the Gwastaden rocks.

From what we have gathered, the history of deposition seems to be somewhat as follows. After the Gwastaden rocks were laid down, the sea-floor was elevated into land and denuded. During the elevatory period a great hollow was scoured out to the west. Rapid sinking then followed, and into the eroded basin the sea entered, filling the cavity with the Caban sediments. At the commencement of the Pale Shale period the hollow was practically levelled up; and, as sinking proceeded, the Rhayader muds were deposited over the sediments of both the Caban and the Gwastaden epochs.

(*b*) Comparison with the Deposits of other Areas.

The accompanying Tables (I & II) show the geological range and distribution of the Rhayader fossils in Britain and abroad. The first set of columns in each table indicates the arrangement of the fossils in the various groups of the Rhayader district; the others their distribution in several British and foreign localities, for the purpose of correlation. (See also Table III, p. 128.)

Taking, first, those fossils of the Rhayader rocks which occur also in the Silurian rocks of Southern Scotland. It is an easy matter to prove that the Rhayader graptolite-forms answer as a whole to the fauna of the Valentian rocks of that region, and that the ascending succession of the species is the same in both areas. The Gwastaden Group represents the Lower Birkhill or Lower Llandovery, the Caban Series the Upper Birkhill, while the Rhayader Pale Shales present us with the fossils of the succeeding Gala or Tarannon Group.

A careful examination of Tables I & II (facing this page) shows that, out of a total number of 29 species of graptolites contained in the Gwastaden rocks (new and uncertain forms included), 21 have been found in the Lower Birkhill Group, while only 13 of these occur in the Upper Birkhill. Of this total quantity, the number of species rigidly confined to the Gwastaden Group is 24, 10 of which are peculiar to the Lower Birkhill, and 1 only to the Upper Birkhill (*Diplograptus sinuatus*, which may be found in the lowest band of the latter). Among these characteristic forms may be specially mentioned *Monograptus fimbriatus*, *M. triangulatus*, *Diplograptus acuminatus*, *D. modestus*, and *Climacograptus rectangularis*,—forms which have never been known to occur outside the Lower Birkhill Shales, or their equivalents, either in the South of Scotland or even throughout the whole of the Silurian rocks of Europe. We can, in fact, parallel every zone in the Gwastaden Group with its representative in the Moffat area. The Cerig Gwynion Grit no doubt takes the place of the 'gingerbread band' at the base of the *D. acuminatus*-zone. At Rhayader, as at Moffat, this zone contains only *Climacograptus normalis* and its varieties. The remainder of this zone is probably represented by the lower half of the Dyffryn Flags, with its restricted *D. acuminatus*. A portion of this latter group, with the addition of the *M. tenuis*-zone, would appear to lie on the same horizon as the zone of *D. vesiculosus*, in which the first Monograptidæ (*M. tenuis*, etc.) with *D. modestus* present themselves. The succession of the life-forms throughout the remaining beds is identical with that of the *M. gregarius*-zone. First in order comes *Monograptus cyphus*; this is followed by the ephemeral *M. triangulatus*, in company with *M. fimbriatus* and *gregarius*, and the first species of *Rastrites*; while towards the summit of the group, the first members of the prolific *M. lobiferus*-family come into view. This is in perfect accord with the order of these forms, as they are

[illegible], Lapw.	...	...	...	...
—— *hybridus*, Lapw.	...	...	...	...
—— *peregrinus*, Barr.	...	...	...	...
Monograptus argutus, Lapw.	...	...	...	...
[illegible], Henk.	...	...	...	..
—— *crenularis*, Lapw.	...	...	...	...
—— *cyphus*, Lapw.	...	...	...	...
[illegible]	...	...	...	...
—— *bina*, Lonsd.	...	...	...	...
Stenopora fibrosa, Goldf.	...	...	...	*

TABLE I.—THE DISTRIBUTION OF THE RHAYADER FOSSILS IN BRITISH DEPOSITS

Species.	Craig Gwynon Grits	Mudstones, Flags and Grits	Rottenstone Beds	Diplograptus modestus Flags	Zone of Monograptus tenuis	Zone of M. cyphus	Zone of M. fimbriatus	Calcareous-Nodule Beds	Zone of M. convolutus	Pale-grey Mudstones	Lower Conglomerate	Intermediate Shales	Upper Conglomerate	M. sedgwicki Grits	Gafallt Shales	Rhayader Pale Shales	Aberystwyth Grits	Metalliferous Slates	Tarannon Shales including Rastrites maximus Zone	Zone of D. acuminatus	Zone of D. vesiculosus	Zone of M. gregarius	Zone of D. convolutus	Zone of M. spinigerus	Zone of R. maximus	Gala or Tarannon Group
	RHAYADER DISTRICT. Gwastaden Group									Caban Group							NORTH & MID WALES			SOUTHERN SCOTLAND						
		Dyffryn Flags			Dôl Shales			Gigrin Mudstones			Caban Conglomerates			Gafallt Beds			Aberystwyth and Devil's Bridge	Cwm Symlog	Conway	Birkhill Shales – Llandovery Formation: Lower Birkhill			Upper Birkhill			
Rastrites distans, Lapw.																•			•						•	•
— *hybridus*, Lapw.																							•	•		
— *peregrinus*, Barr.								•										•				•	•			
Monograptus argutus, Lapw.							•		•										•			•	•	•		•
— *attenuatus*, Hopk.						•	•	•											•		•	•	•	•	•	•
— *Becki*, Barr.																•			?					•	•	•
— [illegible]																	•	•						•		
— *communis*, Lapw.							•															•				
— [illegible]									•																	
— [illegible], Lapw.							•	•	•		•						•	•					•			
— *cyphus*, Lapw.						•												•	•			•				
— [illegible], Lapw.																•			•					•		•
— *crispus*, Lapw.																			•							•
— *decipiens*, Tornq.														?												
— *discus*, Tornq.																•										•
— *distans*, Portl.																•	•							•		
— *exiguus*, Nich.																•			•							•
— *fimbriatus*, Nich.							•															•				
— *galaensis*, Lapw.																•			•							•
— [illegible], Barr.																			•							
— [illegible], Lapw.							•	•										•					•			
— *harpago*, Tornq.														?												
— [illegible], Perner																•										
— *inopinus*, Tornq.									•																	
— *intermedius*, Carr.																•		•							•	
— [illegible], Lapw.														•		•		•	•						•	
— [illegible], Lapw.																•			•					•	•	•
— [illegible], M'Coy								•	•			•		•	•	•	•	•	•			•	•	•	•	•
— — var. *undulatus*, Perner																•										
— *leptotheca*, Lapw.							•	•														•	•			
— *Marri*, Perner																										
— *Nicoli*, Harkn.								•	•																	
— *nodifer*, Tornq.																•			•							
— *nudus*, Lapw.																•			•							•
— *nuntius*, Barr.									•																	
— *pandus*, Lapw.																•			•							•
— *priodon*, Bronn																•			•							•
— *Proteus*, Barr.									•					•	•				•				•	•	•	•
— *revolutus*, Kurck																										
— *runcinatus*, Lapw.																•		•	•						•	•
— *Sandersoni*, Lapw.																						•				
— *Sedgwicki*, Portl.														•	•	•	•	•						•	•	•
— *spinigerus*, Nich.														•					•					•		•
— [illegible], Gein.														•		?	•	•				•	•	•	•	•
— *tenuis*, Portl.					•												?	?			•		•	•		
— *triangulatus*, Harkn.							•															•				
— *turriculatus*, Barr.																•	•		•						•	•
Dimorphograptus elongatus, Lapw.		?																		•	•					
Petalograptus latus, Barr.							•															•	•	•	?	
— *minor*, Elles							•															•				
— *palmeus*, Barr.								•											•			•	•	•	•	•
— *tenuis*, Barr.																•						•	•	•	•	•
Diplograptus acuminatus, Nich.		•																		•						
— *bellulus*, Tornq.									•													•				
— *Hughesi*, Nich.														•				•	•			•	•	•	•	
— *longissimus*, Kurck			•	•																						
— *magnus*, sp. nov.							•	•																		
— *modestus*, Lapw.			•	•																	•					
— *sinuatus*, Nich.							•							•				•	•				•	•	•	
— *tamariscus*, Nich.							•		•									?	•			•	•	•	•	•
Climacograptus extremus, sp. nov.																•										
— *medius*, Tornq.																										
— *normalis*, Lapw.	•	•	•	•	•	•	•		•	•	•	•		•					•	•	•	•	•	•	•	
— *parvulus*, sp. nov.		•																								
— [illegible], Tornq.							?																			
— *rectangularis*, M'Coy					•	•	•	•														•				
— *undulatus*, Kurck							•	•	•																	
Retiolites obesus, Lapw.																•			•							•
— *perlatus*, Nich.														•									•	•	•	
Dictyonema corrugatellum, Lapw.														•			•									
— *delicatulum*, Lapw.														•			•									•
— [illegible], Lapw.																	•									•
— sp.		•																								
Calyptograptus digitatus, Lapw.														•			•									
Nidulites favus, Salt.		?																								
Favosites gothlandicus, Fougt				•										•		•										
— sp.													•													
Lindstroemia sp.				•									•			•										
Petraia elongata, Phil.		?																								
— *lata*, Lonsd.													•			•										
Stenopora fibrosa, Goldf.				•												•										
Crinoid stems		•											•	•			•									
Worm-trails														•	•	•	•	•								
Tentaculites anglicus, Salt.		?																								
Atrypa imbricata, Sow.																?										
— *marginalis*, Dalm.		?																								
— *reticularis*, Linn.																•										
— sp.				•																						
Leptæna sericea, Sow.																?										
— (*Strophomena*) *rhomboidalis*, M'Coy				•												•										
— (*Plectambonites*) *transversalis*, Wahl.		•		•												•										
— sp.										•																
Meristella sp.																•										
Orthis (*Platystrophia*) *biforata*, Schl.		?																								
— *calligramma*, Dalm.																•										
— (*Dalmanella*) *elegantula*, Dalm.				•												•										
— (—) *testudinaria*, Dalm.		•		•																						
— sp.				•											•		•									
Pentamerus sp.			•													•										
Rhynchonella sp.													•	•	•											
Spirifera plicatella, Linn., var. *radiata*, Sow.																?										
— sp.																•										
Strophomena pecten, Linn.																?										
Orthoceras sp.		•					•			•							•									

To face p. 126.]

TABLE II.—COMPARATIVE TABLE OF THE RHAYADER GRAPTOLITES, SHOWING THEIR ORDER OF APPEARANCE IN TIME AND THEIR GEOLOGICAL RANGE AND DISTRIBUTION.

Column key. RHAYADER DISTRICT: 1 Caerig Gwynion Grits; Gwastaden Group — Dyffryn Flags: 2 Micaceous Flags and Grits, 3 Rottenstone Beds, 4 [illegible]; Ddôl Shales: 5 Zone of Monograptus tenuis, 6 Zone of M. [illegible], 7 Zone of M. [illegible]; Gigrin Mudstones: 8 Calcareous-Nodule Beds, 9 Zone of M. convolutus, 10 Pale Grey Mudstones; Caban Group — Caban Conglomerates: 11 Lower Conglomerate, 12 Intermediate Shales, 13 Upper Conglomerate; Gafallt Beds: 14 M.-Sedgwicki Grits, 15 Gafallt Shales; 16 Rhayader Pale Shales. LAKE DISTRICT, Stockdale Shales — Skelgill Beds: 17 Zone of D. [illegible], 18 Zone of D. confertus, 19 Zone of M. fimbriatus, 20 Zone of M. argenteus, 21 Zone of M. convolutus, 22 Band with M. Clingani, 23 Zone of M. spinigerus, 24 Zone of Rastrites maximus; Lower Browgill Beds: 25 Zone of M. turriculatus, 26 Zone of M. crispus. SOUTHERN SCOTLAND, Birkhill Shales = Llandovery Formation — Lower Birkhill: 27 Zone of D. [illegible], 28 Zone of D. vesiculosus, 29 Zone of M. gregarius; Upper Birkhill: 30 Zone of D. cometa, 31 Zone of M. spinigerus, 32 Zone of [illegible]; 33 Gala or Tarannon Group. SWEDEN, Scanian Rastrites-beds: 34 Zone of D. acuminatus, 35 Zone of M. cyphus etc., 36 Zone of M. [illegible], 37 Zone of D. folium, 38 Zone of D. [illegible], 39 Zone of M. [illegible], 40 Zone of M. [illegible].

Area	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
North of Rhayader	*Monograptus crispus*, Lapw.																																								
	—— *discus*, Tornq.																																								
	—— *nodifer*, Tornq.																																								
Eastern Areas, Rhayader	*Monograptus exiguus*, Nich.																																								
	—— *galaensis*, Lapw.																																								
	—— *Holmi*, Perner																																								
	—— *Marri*, Perner																																								
	—— *nudus*, Lapw.																																								
	—— *priodon*, Bronn																																								
	Retiolites obesus, Lapw.																																								
Central & Western Areas	*Rastrites distans*, Lapw.																																								
	Monograptus Becki, Barr.																																								
	—— *crassus*, Lapw.																																								
	—— *distans*, Portl.																																								
	—— *intermedius*, Carr.																																								
	—— *jaculum*, Lapw.																																								
	—— *lobiferus* var. *undulatus*, Perner																																								
	—— *pandus*, Lapw.																																								
	—— *runcinatus*, Lapw.																																								
	—— *turriculatus*, Barr.																																								
	Petalograptus palmeus, var. *tenuis*, Barr.																																								
	Climacograptus extremus sp. nov.																																								
	Rastrites hybridus, Lapw.																																								
	Monograptus Clingani, Carr.																																								
	—— *decipiens*, Tornq.																																								
	—— *barjugi*, Tornq.																																								
	—— *involutus*, Lapw.																																								
	—— *Sedgwickii*, Port.																																								
	—— —— var. *spinigerus*, Nich.																																								
	—— *spiralis*, Gein.																																								
	Diplograptus Hughesii, Nich.																																								
	Dictyonema corrugatellum, Lapw.																																								
	—— *delicatulum*, Lapw.																																								
	—— *venustum*, Lapw.																																								
	Calyptograptus digitatus, Lapw.																																								
	Retiolites perlatus, Nich.																																								
	Monograptus convolutus, His.																																								
	—— *gemmatus*, Barr.																																								
	—— *inopinus*, Tornq.																																								
	—— *nuntius*, Barr.																																								
	—— *Proteus*, Barr.																																								
	Diplograptus bellulus, Tornq.																																								
	Monograptus lobiferus, M'Coy																																								
	—— *Nicoli*, Hark.																																								
	Rastrites peregrinus, Barr.																																								
	Petalograptus palmeus, Barr.																																								
	Monograptus leptotheca, Lapw.																																								
	Diplograptus magnus sp. nov.																																								
	Climacograptus undulatus, Kurck																																								
	Petalograptus minor, Elles																																								
	Monograptus argutus, Lapw.																																								
	—— *crenularis*, Lapw.																																								
	Diplograptus tamariscus, Nich.																																								
	Monograptus triangulatus, Hark.																																								
	—— *gregarius*, Lapw.																																								
	Diplograptus sinuatus, Nich.																																								
	Climacograptus phrygionius, Tornq.																																								
	Petalograptus palmeus var. *latus*, Barr.																																								
	Monograptus communis, Lapw.																																								
	—— *fimbriatus*, Nich.																																								
	Monograptus attenuatus, Hopk.																																								
	—— *cyphus*, Lapw.																																								
	—— *revolutus*, Kurck																																								
	—— *Sandersoni*, Lapw.																																								
	Monograptus tenuis, Portl.																																								
	Climacograptus rectangularis, M'Coy																																								
	Climacograptus medius, Tornq.																																								
	Diplograptus longissimus, Kurck																																								
	—— *modestus*, Lapw.																																								
	Dimorphograptus elongatus, Lapw.																																								
	Diplograptus acuminatus, Nich.																																								
	Climacograptus parvulus sp. nov.																																								
	Climacograptus normalis, Lapw.																																								

NOTE.—Graptolites included within the same brace make their first appearance in association at the same horizon.

developed in the Lower Birkhill Shales; and we may safely assume that the deposits of the two formations belong to the same geological period. One interesting fact, however, should be remembered: a thickness of over 1800 feet in the Rhayader district is equivalent to only 52 feet in the Moffat area; but every zone in this 1800 feet has its proper place in that narrow band of the Southern Uplands of Scotland.

Turning to the Caban Group, we find that 12 out of the 16 different forms contained in the group have been identified from the Upper Birkhill Shales, while only 4 occur in the underlying beds. Of these 4, *Monograptus lobiferus* and *Climacograptus normalis* are common to both the Gwastaden and the Caban rocks. *M. spinigerus* and *M. Clingani* are of restricted range, and have never been detected out of the Upper Birkhill beds. There can be little doubt that the *M.-Sedgwickii* Grits are equivalent to part, at least, of the *M.-spinigerus* zone of Dobb's Linn. The *D.-cometa* bands of Moffat would then probably find their representatives in the lower division of the Caban Conglomerates. There is not, as yet, unfortunately, sufficient fossil evidence from the Gafallt Shales to justify us in placing them in either one of the *M.-spinigerus* or *Rastrites-maximus* zones. We must, therefore, leave them as occupying some position between the two.

A comparison of the Rhayader Pale Shales with the Gala Group yields remarkable results. Of 19 graptolite species contained in the former beds, 16 occur in the latter, and 11 in the Upper Birkhill. If we throw in the *R.-maximus* zone with the Gala beds, no less than 18 out of the 19 species are identical in the two groups, while the 11 in the Upper Birkhill are reduced to 5. The forms yielded by these pale shales at the Tannery and the exposures west of Rhayader doubtless belong to the *R.-maximus* beds of Moffat. Such species as *M. crassus* and *M. turriculatus* are more characteristic of the highest zones of the Upper Birkhill than of the lowest beds of the true Gala Group. On the other hand, *M. exiguus*, *M. priodon*, *M. galaensis*, *Retiolites obesus*—common to the eastern area—are true Gala forms, and are seldom, if ever, detected at lower horizons. It seems only right, therefore, to consider the Rhayader Pale Shales as the representatives of the Gala and part of the Upper Birkhill Groups. We are thus confronted with the old difficulty of separating the Upper Llandovery from the Tarannon Shales, and one which may prove troublesome in future research among these Valentian rocks, unless some definite line is to be drawn dividing the two. If the zonal method of mapping is to be followed, no complications should arise. If, on the other hand, a hard-and-fast line must be drawn, then it should be a palæontological, and not a petrological line. The division that naturally suggests itself is one that has already been followed out in the mapping of these rocks at Conway.[1] In that locality the Upper Llandovery and the Tarannon Shales were

[1] Quart. Journ. Geol. Soc. vol. lii (1896) p. 273.

TABLE III.—CORRELATION OF THE RHAYADER ROCKS.

RHAYADER DISTRICT.	SOUTHERN SCOTLAND.	WALES.	SWEDEN.
RHAYADER PALE SHALES.	GALA GROUP.	TARANNON SHALES.	*RETIOLITES*-SKIFFER.
CABAN GROUP. GAFALLT BEDS. Gafallt Shales. *Monograptus-Sedgwickii* Grits. CABAN CONGLOMERATES. Upper Conglomerate. Intermediate Shales. Lower Conglomerate.	UPPER BIRKHILL. Zone of *Rastrites maximus*. Zone of *Monograptus spinigerus*. Zone of *Diplograptus cometa*.	MAY HILL or UPPER LLANDOVERY, including ABERYSTWYTH GRITS and part of the METALLIFEROUS SLATE-GROUP.	*RASTRITES*-SKIFFER. Zone of *Monograptus runcinatus*. Zone of *M. Sedgwickii*. Zone of *Diplograptus cometa*.
GWASTADEN GROUP. GIGRIN MUDSTONES. Pale Grey Mudstones. Zone of *M. convolutus*. Calcareous-Nodule Beds. DDÔL SHALES. Zone of *M. fimbriatus*. Zone of *M. cyphus*. Zone of *M. tenuis*. DYFFRYN FLAGS. *Diplograptus-modestus* Flags. Rottenstone Beds. Micaceous Flags and Grits. CERIG GWYNION GRITS.	LOWER BIRKHILL. Zone of *Monograptus gregarius*. Zone of *D. vesiculosus*. Zone of *D. acuminatus*.	LOWER LLANDOVERY.	Zone of *D. folium*. Zone of *M. triangulatus*. Zone of *M.* cf. *cyphus*. Zone of *D. acuminatus*.
BLUE-BLACK SHALES.	UPPER HARTFELL.	BALA.	*TRINUCLEUS*-SKIFFER.

separated at the base of the *Monograptus-exiguus* zone. This fossil is one of the first to be found in the Gala Beds, as at Glenkiln Barn and elsewhere, and has never been detected in the underlying black shales.

In Central Wales we have the equivalents of the Caban Group in the Aberystwyth Grits and a portion of the so-called 'Metalliferous' Slates; it is not unlikely, however, that only the Gafallt Beds are the true representatives of these western rocks. The *Monograptus-Sedgwickii* Grits strongly resemble the beds of the Aberystwyth Group, in the regular succession of evenly-bedded, fine-grained grits and shales. Moreover, the occurrence of the dendroid graptolites, so characteristic of the Gafallt Beds, in addition to *Monograptus Clingani*, points almost conclusively to their occupancy of the same stratigraphial parallel. *M. turriculatus*, which is quoted from these West Caerdiganshire rocks, is a higher form, but it was detected at a distance of over 1½ miles west of Aberystwyth, in the cliffs of which town the grits are best developed. Probably, therefore, it has been extracted from the top of the group.[1]

Referring once more to the Rhayader Pale Shales, we see that they bear a rigid comparison with the Tarannon Shales of Conway; for, of the 19 graptolites quoted from the former, 9 appear in the latter; and if we add the *Rastrites-maximus* zone to the upper group, the number of common species is increased to 13. The Rhayader Shales, moreover, are exactly of the Tarannon type—pale grey, green, and purple mudstones and shales.

Exception being made of the work of Prof. Hughes and Mr. Marr, the Lower Llandovery formation of North Wales has not hitherto been worked out in any detail. From the researches of those authors, however, it becomes evident that the Corwen[2] and Cerrig-y-druidion Grits[3] fall naturally into line with the Cerig Gwynion Grits—the base of the Silurian system.

Though no zonal work has yet been completed on the Valentian rocks of South Wales, the boundaries of the main divisions, as they occur along the south-eastern fringe of the Central Wales complex, are fully indicated on the maps of the Geological Survey. Along this fringe the broad grouping of the various formations bears satisfactory comparison with the arrangement of their equivalents in the Rhayader district. In the vicinity of Llandovery, the Tarannon Shales rest with apparent conformity on Upper Llandovery rocks. Near Newbridge, where they emerge from beneath the Wenlock Shales, they are again seen to overlie the same beds; but as the village is approached from the westward, they rapidly pass over the latter on to the Lower Llandovery, and eventually come to rest on rocks of Ordovician age. The district that has been examined in the neighbourhood of Rhayader is, unfortunately, not of sufficient

[1] Quart. Journ. Geol. Soc. vol. xxxvii (1881) p. 167.
[2] *Ibid.* vol. xxxiii (1877) p. 207.
[3] *Ibid.* vol. xxxvi (1880) p. 278.

extent to prove that the unconformity between the Tarannon Shales and the Lower Llandovery is so strongly marked as in these southern areas; but, as already suggested, it is probable that, if the Rhayader Pale Shales were followed eastward, they would be found in time to have completely overlapped the beds of the Gwastaden Group.

This epoch of subsidence and burial by overlap appears to have been continuous in and around Wales up to Old Red Sandstone times; for, in the same way, the Wenlock, Ludlow, and Old Red Sandstone beds all pass, in turn, over the outcrops of their underlying rocks on to those of greater antiquity.

In this southern district, again, it is well known that a strong unconformity exists between the Upper and Lower Llandovery formations—an unconformity representing elevation, denudation, and subsidence between the two periods of deposition. This is in exact accordance with the results now obtained in the Caban Côch area.

For a detailed zonal comparison of the rocks of the Rhayader Series with those of the Lake District, Southern Scotland, and Sweden, the reader is referred to Table II, facing p. 126.

It is evident that in the Rhayader succession we have the entire series of formations which answer to the Valentian Group of Southern Scotland, a group which is universally admitted to include the representatives of the Lower Llandovery, Upper Llandovery, and the Tarannon Groups of Wales. In Southern Scotland this Valentian succession contains extremely varied lithological types: a thin black-shale series (the Lower and Upper Birkhill) forming its two lower divisions, and a massive grit or grauwacke series (the Gala Group) its upper member. But the whole series is bound together, as an unit, by the ascending sequence of the various graptolite-species that mark its successive beds. The corresponding formations of Wales and the West of England—the Lower Llandovery, Upper Llandovery, and Tarannon Groups—have been studied hitherto in areas where only one member existed in force; or, if two or more members were present, they varied in lithological characters, and were separated by marked unconformity; while their fossils were almost wholly brachiopoda, trilobita, and the like. In this Rhayader region, for the first time in Southern Britain, do we find the Valentian succession, in which the whole, or practically the whole, of the strata belonging to the Lower Llandovery, Upper Llandovery, and the Tarannon are in a grand sequence of rocks possessing a more or less common lithological character and a fauna composed throughout of similar palæontological types. The whole Valentian succession of Rhayader falls very naturally into three distinct members—the Gwastaden Group or Lower Llandovery, the Caban Group or Upper Llandovery, and the Rhayader Pale Shales or Tarannon; and each of these members breaks up into subdivisions marked by characteristic graptolites. It is, therefore, not unlikely that the Rhayader Series, in which the sequence is so certain and the graptolite-fauna so definite,

will become, in time, the standard by means of which future geologists will unravel even the tantalizing complex of Central Wales, and bring into line the many scattered and isolated patches of the Llandovery and Tarannon rocks which surround it.

In conclusion, I wish to express my indebtedness to Prof. W. W. Watts, M.A., Sec.G.S., who has furnished me with descriptions of microscopic slides of the various local rocks; to Mr. C. A. Matley, B.Sc., F.G.S., for the identification of the greater number of the brachiopoda which have been obtained from the district; and to my former colleagues, Mr. W. S. Becher, A.M.I.C.E., and Mr. G. Waterhouse, Stud.Inst.C.E., for occasional assistance. I am personally responsible for the identification of the graptolites; but a few doubtful species were referred to Miss E. M. R. Wood. Finally, the continued interest of my father, Prof. C. Lapworth, F.R.S., has greatly encouraged me in carrying out the researches described in this paper.

IV. Appendix.

On New Species of Graptolites from the Rhayader District.

The following new species of graptolites have been detected in the course of my investigations in the field. While recognizing the evil effects which result from the straining of minute palæontological distinctions to an excessive degree, and the introduction of new forms, many of which are useless and unnecessary, I am of opinion that the species described below are so distinctive in their peculiarities, and so characteristic of certain zones in the Rhayader district, that they deserve an introduction into the society of recorded species. They form in every case the predominant fossils of their own particular zones. For this reason, the descriptions of these graptolites may be of use to future investigators in Central Wales; useful, perhaps, when they are the only fossils obtainable, and at a time when one must perforce be content with the few gifts of this kind which Nature has provided.

Climacograptus parvulus, sp. nov. (Figs. 20 a & 20 b, p. 132.)

Mature rhabdosoma.—The rhabdosoma rarely exceeds $\frac{1}{10}$ to $\frac{1}{6}$ inch in length, with an average breadth of about $\frac{1}{20}$ inch. The thecæ number from 4 to 6 in the length of the rhabdosoma, and are at a distance of $\frac{1}{35}$ to $\frac{1}{42}$ inch apart. They are somewhat similar to those of the *Climacograptus scalaris*-type. The excavations, however, seem relatively larger, the vertical or slightly inclined exterior margins occupying only about half the distance between the adjacent apertures. The virgula is completely visible in the obverse aspect; it does not, however, appear to be prolonged beyond the youngest thecæ.

Proximal end.—The sicula attains a length of about $\frac{1}{30}$ inch. Its dorsal wall is free for about one-fourth to one-third of its

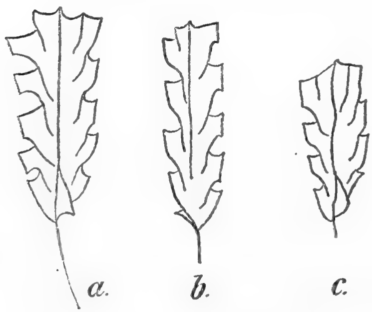
apparent length. The primary theca appears to have grown slightly below the aperture of the sicula. The virgella is produced from $\frac{1}{10}$ to $\frac{1}{20}$ inch beyond the proximal end of the sicula.

Fig. 20 A.—Climacograptus parvulus, *sp. nov.* (*nat. size*).

a b c

a & *c*=obverse aspect; *b*=reverse aspect.

Fig. 20 B.—*The same* (×5).



In the reverse aspect a small fraction of the aperture of the sicula is always seen projecting below the first theca of the secondary series. An impressed septal furrow seems to be present, commencing between the first and second thecæ of the primary series.

There can be little doubt as to the justifiability of the separation of this minute form as a distinct species. It occurs only on one horizon in the Rhayader district, where it forms the commonest fossil; and it never varies to any extent from the above dimensions.

This form bears a superficial resemblance to *Climacograptus minutus*, Carr., but differs from it

(1) In size, being smaller and proportionately broader;
(2) In the deeper excavations above the thecal apertures; and
(3) In having an extension of the virgella, and no prolongation of the virgula.

Horizon.—Dyffryn Flags, Gwastaden Series, in the Rhayader District, in conjunction with *Diplograptus acuminatus*, Nich.

DIPLOGRAPTUS MAGNUS, sp. nov. (Fig. 21 *a–d*, p. 133.)

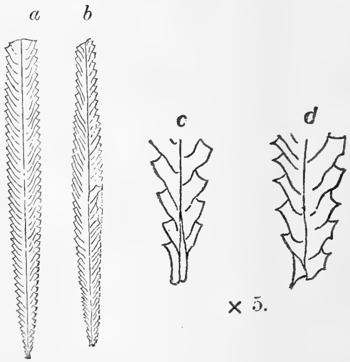
Mature rhabdosoma.—The rhabdosoma reaches a length of at least $1\frac{2}{3}$ inches. Commencing with a more or less pointed proximal end, it increases in width gradually and uniformly to about one-half or five-eighths of its whole length from the proximal end. Here it attains its maximum width; from this point upward it gradually decreases, and at the distal end its breadth is only about five-sixths of the maximum. The average measurements are as follows:—

	Inch
Width at the top of the 2nd thecæ (prim.)	=0·04
" " 10th " "	=0·10
Maximum width at five-eighths of the length from the proximal end	=0·17
Width at the distal end	=0·15

The thecæ vary greatly in their size and inclination: at the proximal end they number from 33 to 34 in the inch, with a length of 3 to 4 times their breadth, and inclined at about 37° to the

virgula. Distally only 24 to 26 occur within the length of 1 inch, each theca being about 5 times as long as broad, and inclined at an angle of about 25°. They present the appearance of cylindrical tubes overlapping one another from two-thirds to three-fourths of their length; they usually contract at their junction with the apertures of the preceding thecæ, and again expand towards their own apertures. The form of the free portions of the thecæ varies with the amount of compression to which the graptolite has been subjected, sometimes resembling the *Climacograptus*-type, with external margins nearly vertical and proximal edges horizontal, or appearing in the form of straight inclined tubes with parallel margins and concave apertures perpendicular to the direction of the thecæ. The lines of growth are generally well exhibited under a low microscopic power.

Fig. 21.—Diplograptus magnus, *sp. nov.* (a & b, *nat. size*; c & d, ×5).



a=Obverse aspect, restored.
b=Reverse aspect of an abnormally contracted specimen, drawn from the actual specimen.
c=Proximal end: obverse, restored.
d=Proximal end: reverse, drawn from the actual specimen.

A straight median line is always distinct in obverse aspect, and in the reverse view the impressed furrow runs from end to end of the rhabdosoma. There appears to be no prolongation of the virgula distally, or of the virgella at the proximal end.

Proximal end.—The sicula has a constant length of $\frac{1}{16}$ inch. Its apex reaches the level of the second aperture on the primordial series, and appears to be completely visible in obverse aspect. It is free on its dorsal side for about one-third of its length, and in reverse aspect nearly the whole of this length is exposed. The first theca has apparently grown downward, and extended a short distance below the proximal end of the sicula, with a total length of about two-thirds of the latter.

This species is most closely allied to *Diplograptus truncatus*, Lapw. and *D. palmeus*, Barr. From the former it may be easily separated by

(1) The size of the mature rhabdosoma;
(2) The absence of spines, and the general characters of the proximal end,
(3) The presence of a visible virgula; and
(4) The form and inclination of the thecæ.

From *Diplograptus palmeus* it is distinguished by

(1) The size and form of the mature rhabdosoma; and
(2) The characters of the proximal end.

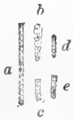
Horizon.—Zone of *Monograptus fimbriatus*, in the Gwastaden Series of the Rhayader District, with *M. fimbriatus*, Nich., *M. gregarius*, Lapw., *Climacograptus undulatus*, Kürck., etc.

Climacograptus extremus, sp. nov. (Figs. 22 A & 22 B, *a–e*.)

? *Diplograpsus teretiusculus*, His., Richter, Zeitschr. Deutsch. Geol. Gesellsch. vol. v (1853) p. 456 & pl. xii, figs. 11–13.

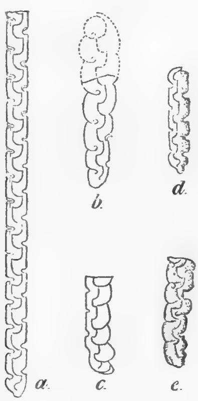
Mature rhabdosoma.—The rhabdosoma has an average length of $\frac{1}{10}$ to $\frac{1}{5}$ inch; and in one case I have detected an abnormally developed specimen having a length of $\frac{2}{5}$ inch. The width varies from $\frac{1}{50}$ (normal) to $\frac{1}{25}$ inch. Above the rounded nose of the proximal end the breadth usually remains constant throughout the rhabdosoma. The thecæ alternate regularly, numbering from 38 to 48 in the inch. The excavations about the thecal apertures are unusually small; and, indeed, in many specimens no excavations are to be seen.

Fig. 22 A.—Climacograptus extremus, *sp. nov.* (*nat. size*).



a = Abnormally long specimen.
b–e = Normal examples.

Fig. 22 B.—*The same* (× 5).



The chief characteristic of this beautiful little graptolite is the sutural groove which zigzags from side to side, swinging from immediately below the aperture of one theca to a corresponding position in the succeeding theca of the opposite series. In well-preserved and incompressed specimens, the thecæ are seen presenting the appearance of a pair of lips which completely envelop the walls of the excavations above the apertures. The external margins of the thecæ may be vertical, or strongly concave. The thecal partitions are sometimes represented as fine lines extending for a short distance below the mouth of the orifices.

Proximal end.—There does not appear to be either an extension of the virgella or prolongation of the virgula; nor in any of my examples have I been able to trace a sign of a sicula: possibly it may be enveloped within the primary thecæ.

This species differs from *Climacograptus undulatus*, Kürck. in

(1) The size of the rhabdosoma;
(2) The characters of the proximal end; and
(3) The form of the thecæ.

From *Diplograptus Hughesii*, Nich., to which it bears a certain resemblance, it may be distinguished by

(1) The width of the rhabdosoma; and
(2) The form and length of the thecæ.

Horizon.—The base of the Rhayader Pale Shales, where it forms the commonest fossil. Found in conjunction with *Monograptus crassus*, Lapw., *M. pandus*, Lapw., *M. Becki*, Barr., etc.

[With reference to the question asked by Mr. Marr in the course of the discussion which followed the reading of this paper, I have inserted the following description of

DIPLOGRAPTUS MODESTUS, Lapw.

1876. *Diplograptus modestus*, Lapw., Lapworth, Catal. Western Scot. Foss. pl. ii, fig. 33.

1877. *Diplograptus confertus*, Nich., Lapworth, 'Graptolites of County Down' Proc. Belfast Nat. Field Club, App. pl. vi, fig. 8.

1897. *Diplograptus modestus*, Lapw., Perner, 'Graptolites de Bohême' pt. iii, p. 5 & pl. x, fig. 8.

This species has been figured in the publications mentioned above, but without description. The following are the essential characters of the species, as noted in the MSS. of Prof. Lapworth :—

Rhabdosoma simple, diprionidian, with parallel margins, and an obtusely pointed base; from 1 to $1\frac{1}{2}$ inches in length, and $\frac{1}{10}$ inch in width. There is an extension of the virgella of $\frac{1}{8}$ to $\frac{1}{4}$ inch long. Virgula prolonged beyond the youngest hydrothecæ for a length of $\frac{1}{4}$ or even $\frac{1}{2}$ inch.

Hydrothecæ 26 to 30 in the inch, inclined at an angle of about 30° to the axis of the rhabdosoma, quadrangular in section or very slightly rounded. Apertural margins somewhat concave, at right angles to the axis of the rhabdosoma and prolonged in an acute denticle. Outer margins of hydrothecæ slightly convex.

This species is recognizable by its comparatively small size, its breadth, the concave apertural margins, and the convex margins of the hydrothecæ.

Horizon.—Lower Birkhill. Very common in the *Diplograptus-vesiculosus* zone at Dobb's Linn, etc., Moffat; and in the *D.-modestus* Flags of the Gwastaden Group, Rhayader.—December 8th, 1899.]

EXPLANATION OF PLATES VI. & VII.

Plate VI.

Detailed Vertical Section of the Strata of the Rhayader Sequence, on the scale of 300 feet to the inch.

Plate VII.

General Geological Map of the Rhayader District, on the scale of $1\frac{1}{2}$ inches to the mile.

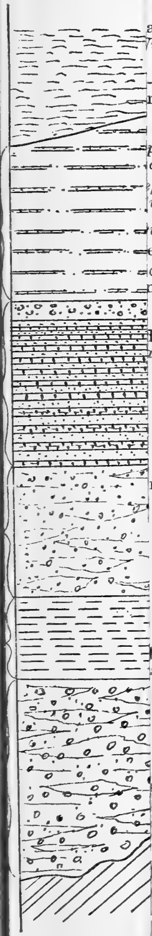
Discussion.

Mr. Marr congratulated the Author on his paper, his map, and the lucid way in which he had placed his results before the Society. He had followed his father, not only in describing Valentian rocks, but in choosing a particularly difficult region for description. The Author spoke of the *Diplograptus-modestus* Beds. He (the speaker) would be glad to know whether that species had ever been described.

The Rev. J. F. Blake said that he had listened with much interest to the paper. The country described seemed to show special stratigraphical features which had been admirably worked out by the Author. When, however, one attempted to assimilate his conclusions some questions arose. The limitation of the conglomerate was most remarkable, and the Author's diagram indicated that he considered this limitation original. There were no doubt, in Central Wales, other limited patches of conglomerate, but their occurrence suggested a question as to the systematic value of the unconformity. There was a suspicious approximation to parallelism in the strata above and below the line of unconformity, which reminded one of text-book figures illustrative of 'contemporaneous erosion.' In this connexion the speaker called to mind the conclusions of the late Walter Keeping, who distinctly asserted, and argued about, the absence of any unconformity here. His explanation of the district was quite different from that of the Author, and if he did not miss the unconformity he must have regarded it as being of no systematic value. It was stated also that graptolites in the beds above and below both belonged to the 'Birkhill' Group, the only distinction being between 'Upper' and 'Lower'; and the speaker thought it unadvisable to perpetuate the confusion arising from such nomenclature in the case of the 'Llandovery,' which included an unconformity in its midst. He also drew attention to some strange results to which we seemed to be led by the guidance of the graptolites. Walter Keeping had united two rocks, one at Aberystwyth and the other at the Devil's Bridge, separated by apparent stratigraphy by nearly 4 miles in thickness of rock, on the strength of their graptolitic fauna being the same—really only 2 out of 8 species agreed, but these were considered the most important; and now we should have similar identifications as far as Rhayader. It was really remarkable that so vast a sweep of country and such enormous thicknesses actually observed in the hills should be referred to one limited 'Birkhill' or 'Llandovery' horizon; and still more remarkable that, though Llandovery itself was almost in sight, the correlation should have to be made by going to Scotland and the Lake District: there being, so far as the speaker could learn, no fossils in common with those of the typical locality, though there were rocks in both places of the same physical character. What had become of all these cubic miles of strata when we passed from Rhayader to Llandovery? The Author's paper was of great value in raising these interesting questions.

Prof. Groom congratulated the Author on an admirable piece of work in a difficult district, but could speak only from a very imperfect acquaintance with the rocks of the Central Wales complex. It would appear from the late Walter Keeping's list of graptolites that the Tarannon Shales and the Upper and Lower May Hill Beds were all probably present in the district; but it had been reserved for the Author to prove this, and show that the succession agreed minutely with that of distant areas. A test of the accuracy of the work might be found in the beautiful way in which it explained the relations between the Silurian and Ordovician rocks, as stated by

y and greenish-grey mudstones and flags, with *Climacograptus*
hoceras sp., etc.



ard blue mudstones with *Monograptus convolutus, M. cre-*
Nicoli, M. lobiferus, Diplograptus bellulus, etc.

-grey and greenish-grey mudstones and flags, with occasional
rbonate of lime.

ptotheca, M. Nicoli, M. lobiferus, M. gregarius, Rastrites pere-
cograptus undulatus, etc.

ptotheca, M. fimbriatus, M. gregarius, Diplograptus magnus,
us rectangularis, Cl. undulatus, etc.

iangulatus, Diplograptus sinuatus, etc.

ed, blue shales and grey flags with *Monograptus fimbriatus*, etc.
ous concretions.
mestone.

l, calcareous, nodular, hard, grey, sandy flags and grey shales,
ptus cyphus, Climacograptus rectangularis, etc., and a band

ring, shivery, blue-and-grey shales, with sandy grey flags,
tenuis, Climacograptus rectangularis, etc.

banded grey-and-blue flags and flaggy shales, with *Diplo-*
stus, D. longissimus, Climacograptus rectangularis, Cl. nor-

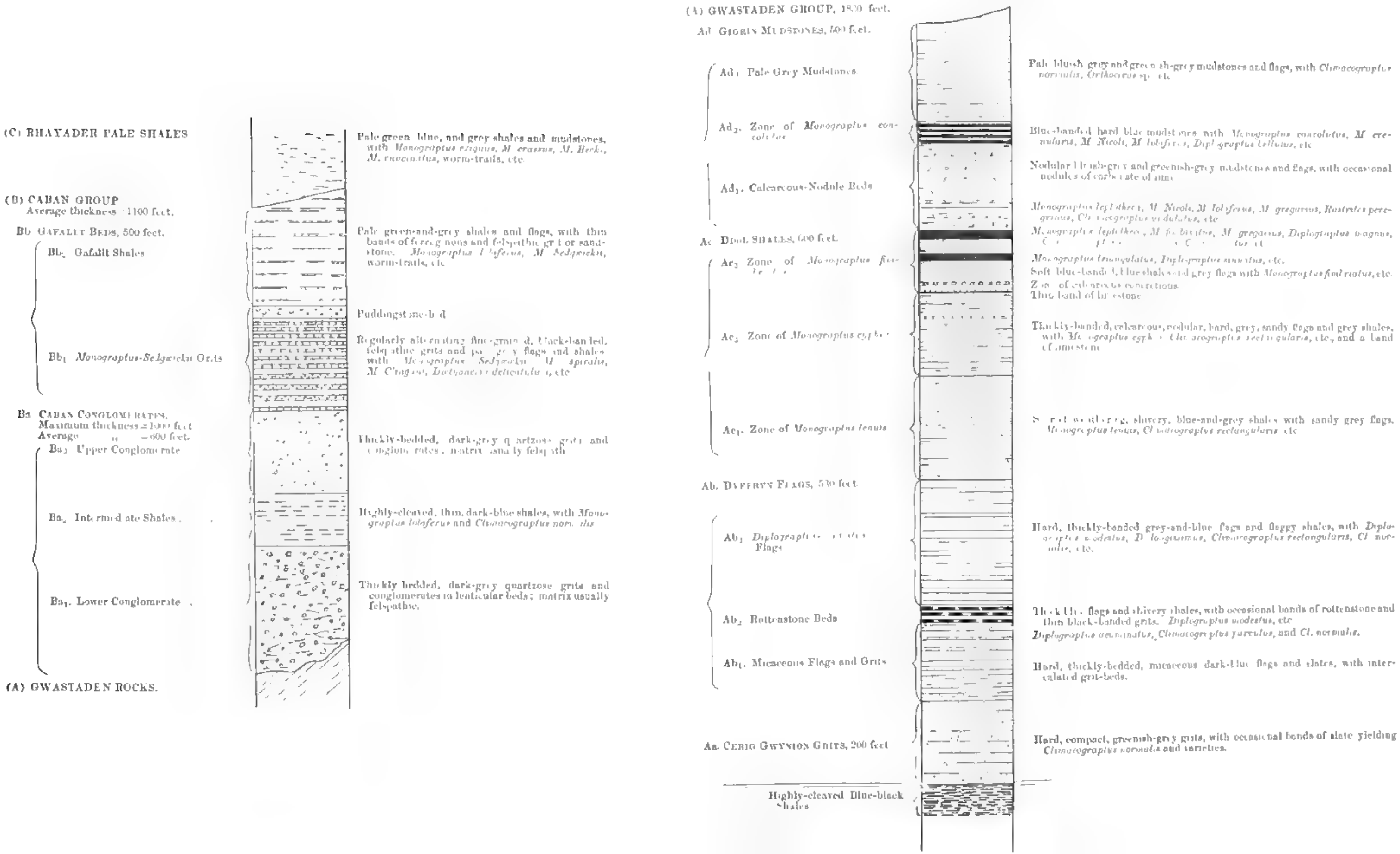
and shivery shales, with occasional bands of rottenstone and
nded grits. *Diplograptus modestus*, etc.
uminatus, Climacograptus parvulus, and *Cl. normalis.*

bedded, micaceous dark-blue flags and slates, with inter-
eds.

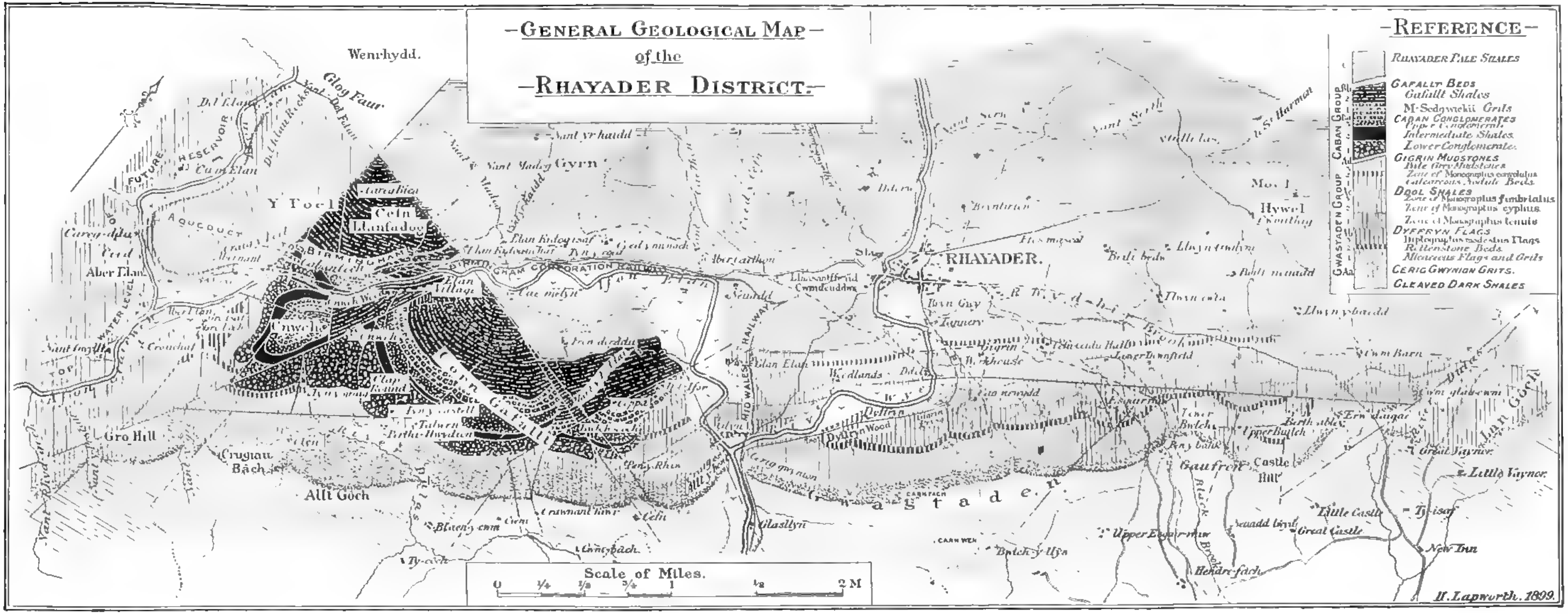
greenish-grey grits, with occasional bands of slate yielding
us normalis and varieties.

Detailed Vertical Section of the Strata of the Rhayader Sequence.

(Scale: 1 inch = 300 feet.)




-REFERENCE-
RHAYADER PALE SHALES.
GAFALLT BEDS.
Gafallt Shales.
M-Sedgwickii Grits.
CABAN CONGLOMERATES.
Upper Conglomerate.
Intermediate Shales.
Lower Conglomerate.
GIGRIN MUDSTONES.
Pale Grey Mudstones.
Zone of Monograptus convolutus.
Calcareous Nodule Beds.
DDÔL SHALES.
Zone of Monograptus fimbriatus.
Zone of Monograptus cyphus.
Zone of Monograptus tenuis.
DYFFRYN FLAGS.
Diplograptus modestus Flags.
Rottenstone Beds.
Micaceous Flags and Grits
CERIG GWYNION GRITS.
CLEAVED DARK SHALES.
CABAN GROUP
GWASTADEN GROUP
to St Harmon
Gelli-las.
Moel Hywel
Cwmithig
Llwyn-Gwilym
Beili-neuadd
Llwyn-cwta
Llwyn-y-baedd
Brook
Downfield
Cwm Barn
River Dulas
Cwm-glas-cwm.
Lan Goch
Lower Bwlch
Berth-abley
Erw-daigae
Upper Bwlch
Pen-y-bank
Gaufron
Castle Hill
Great Vaynor
Little Vaynor
Black Brook
Little Castle
Ty-isaf
Neuadd-lwyd
Great Castle
Esgair-rhiw
New Inn
Hendre-fâch
H. Lapworth. 1899.



GENERAL GEOLOGICAL MAP OF THE RHAYADER DISTRICT.

the officers of the Geological Survey. Unconformable overlap of the Tarannon and Upper Llandovery Series on older beds had been described, but never satisfactorily proved. The Geological Survey had classed the Lower Llandovery with the Ordovician Series, and the speaker would like to ask the Author whether in the Rhayader District there was any evidence of a passage between the two series.

Prof. C. Lapworth said that he had been interested in the Mid-Wales country since the late Walter Keeping had discovered Birkhill graptolites within it, and he had himself pointed out some of its resemblances to the Upland region of Southern Scotland, but he had never found an opportunity of studying any of its geology in detail. It was pleasant to find, from the Author's results, how remarkably the graptolite-fauna of the Rhayader Series corresponded in detail with that of other regions in Britain and North-western Europe. The peculiar phenomena of unconformity and overlap described by the Author were very striking; but they seemed to be in harmony with well-known appearances in other districts, among the strata laid down during that Valentian period of great crust-movement which intervened between the Upper Bala and the Lower Wenlock. He had twice visited the Rhayader District and neighbourhood, and had been struck by the fine development of the conglomerates and grits at Caban Côch and elsewhere, as contrasted with the masses of shales and slates among which they occurred. The whole country seemed to be an ideal one as a source of water-supply—the broader shaly valleys affording admirable sites for impounding-reservoirs, and the narrow rock-bound gorges for retaining-dams. Mr. Mansergh had already brilliantly utilized part of the region for the Birmingham water-supply, and the speaker looked forward to the time when the rest of it would be similarly utilized by Sir Alexander Binnie for the water-supply of London itself.

The President and Sir Alexander Binnie also spoke.

The Author thanked the Fellows for the very kind manner in which they had received his paper. In reply to Mr. Marr, he stated that a drawing of the graptolite *Diplograptus modestus*, Lapw. had been figured as such, but not described. In answer to a question from Prof. Blake, with regard to the relations of the Gwastaden and Caban Groups, he said that the break between the two was more of a stratigraphical than a palæontological nature, as many of the graptolites occurring in the topmost beds of the Gwastaden Group were found in zones well up in the Caban Group. The brachiopoda obtained from the Rhayader district bore satisfactory comparison with those quoted from Llandovery. As to the stratigraphical relations of the Gwastaden and local Bala rocks, the two sets of deposits appeared to be conformable within the limits of the Rhayader District.

8. *On the* Geological Structure *of* Portions *of the* Malvern *and* Abberley Hills. By Prof. T. T. Groom, M.A., D.Sc., F.G.S. (Read November 8th, 1899.)

[Plate VIII—Map.]

Contents.

I. Introduction.

In a former communication[1] an account was given of the structure of the southern portion of the Malvern Range; it is now proposed to supplement this account by a description of the rest of the Malvern Range and of certain portions of the Abberley Range, which were selected with the view of throwing light upon the geological history of the Western Midlands. The structure will be traced

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 129–168 & pls. xiii–xv.

from south to north, beginning with Swinyard Hill, which is situated immediately to the north of the area described in the writer's former paper.

II. Swinyard Hill.

The narrow ridge of Swinyard Hill is separated from Midsummer Hill on the south by the Gullet Pass, and from the Herefordshire Beacon by the depression termed by Phillips[1] the 'Silurian Pass.'

It has been pointed out on a former occasion[2] that the Gullet Pass is traversed by a line of fault. North of this line the width of the Archæan massif suddenly narrows, so that the deposits which flank the hill abut on the south directly against the Archæan mass of Midsummer Hill. The Archæan rocks of Swinyard Hill are well foliated towards the south, and show a marked plagioclinal disposition. The ridge is flanked on each side by May Hill Sandstone, forming ground with a slope decidedly less steep than that of the ridge itself, especially on the eastern side. The change of slope is usually somewhat sudden, and probably marks lines of faulting on each side; but the May Hill Beds are very badly exposed, and their actual junction with the Archæan is not seen. The faulted character of the junctions seems to follow from their usually straight or zigzag course. The two rocks occur one on each side of the narrow path leading through the 'Silurian Pass.' This is the only spot where the May Hill Beds are actually seen *in situ*. They consist here of sandstones and thin impure limestone-bands, such as mark the summit of the May Hill Series. The southern side of the path is apparently formed by the faulted surface of the Archæan; this face dips E. 33° N. at 60°. The sandstones dip north-eastward: that is, directly towards the Archæan of Hangman's Hill, the southerly elevation of the Herefordshire Beacon. These relations suggest that the May Hill Beds are the remnant of a fold which has been overturned from the north-east, and overthrust by the Archæan of the Herefordshire Beacon (see fig. 1, p. 141). The May Hill Beds probably occupy most of the eastern slope of Swinyard Hill, down as far as the faulted boundary of the Trias. Symonds states that 'Wenlock beds . . . have been seen still clinging to the eastern slopes of the Swinyard,' and that 'Wenlock corals have been found beneath the débris, in the garden of the cottage on the slope of the hill above the road to the Gullet quarry.'[3] No traces of these beds have been detected by the present writer. On the other hand, a portion of the upper part of Castlemorton Common is occupied by a southerly extension of the 'Warren House Rocks' (see Map, Pl. VIII), which has hitherto escaped notice.

The Silurian rocks west of Swinyard Hill are nowhere exposed close to the ridge, but abundant traces of the grey upper beds of the May Hill Sandstone may be seen in places. According

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 29.
[2] Quart. Journ. Geol. Soc. vol. lv (1899) p. 148.
[3] 'Old Stones' 2nd ed. (1884) p. 54.

to Symonds,[1] the Cambrian conglomerate was formerly to be seen on the western side of the great quarry, at the southern end of Swinyard Hill. Unfortunately, the relations of this formation to the Archæan rocks of the quarry were not described. The Woolhope Limestone, though badly exposed, may be traced by débris and by the steep slope that it forms, also by occasional exposures along a double line of outcrop on the western slope of Swinyard Hill. The dip of both bands[2] is easterly, and the area to the west and east of the western and eastern bands respectively is occupied by May Hill Sandstone; the limestone, therefore, appears to form an overturned syncline.

The supposed relations of the rocks at the northern end of Swinyard Hill are shown in fig. 1, p. 141.

III. The Herefordshire Beacon.

The Herefordshire Beacon is certainly one of the most imposing and geologically interesting hills in the whole Malvern Range. It is bounded on the south by the 'Silurian Pass,' and on the north by a deep depression running from Wind's Point to Little Malvern.

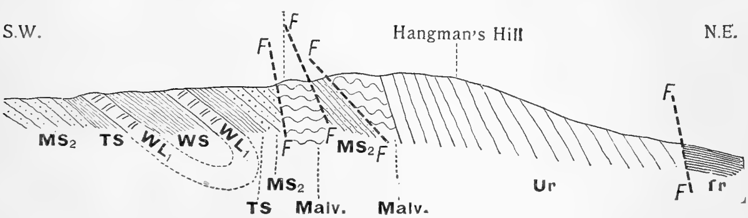
The western and higher part of the hill is composed of rocks of the Malvernian Series; the eastern part is formed by the 'Warren House Rocks' of Hangman's Hill, Broad Down, and Tinker's Hill. These rocks, first regarded by Holl[3] as metamorphosed Cambrian, were compared by Dr. Callaway[4] with the rhyolitic Uriconian Series of Shropshire; they have been studied by Green,[5] and by Mr. Rutley[6] and Mr. Acland.[7] They are shown to consist of rhyolites, andesites, basalts, and tuffs; the bedding sometimes well marked, has a prevailing easterly dip.

The line of junction between the Uriconian and Malvernian Series runs along a marked depression, extending in a north-north-easterly direction from Clutter's Cave, and turning sharply east-north-eastward north of Tinker's Hill. South of Clutter's Cave the junction is marked by no surface-feature; evidently it terminates against the patch of May Hill Sandstone that occupies the 'Silurian Pass.' South of Hangman's Hill the Uriconian Series comes directly into contact with the sandstone. The junction with the Malvernian Series is nowhere actually exposed, but the circumstance that it curves round eastward as it descends to lower levels suggests that the plane of junction dips in that direction. In the absence of detailed knowledge of the disposition of the lava-beds and tuffs, it is at present impossible to determine whether this junction is a fault or a surface upon which the Uriconian series was originally deposited.

[1] 'Old Stones' 2nd ed. (1884) p. 24.
[2] The eastern band is not exposed at any point immediately west of Swinyard Hill, but it is seen dipping eastward near Walm's Well, immediately to the north.
[3] Quart. Journ. Geol. Soc. vol. xxi (1865) pp. 93, 94.
[4] *Ibid.* vol. xxxvi (1880) pp. 536 *et seqq.* [5] *Ibid.* vol. li (1895) pp. 1 *et seqq.*
[6] *Ibid.* vol. xliii (1887) pp. 481 *et seqq.* [7] *Ibid.* vol. liv (1898) pp. 556 *et seqq.*

The rocks of the Malvernian Series form the most conspicuous part of the Herefordshire Beacon. Towards the west this mass bulges out in a way suggestive of igneous intrusion into the Silurian Series. The rocks are, as a whole, massive rather than

Fig. 1.—*Section across the northern extremity of Hangman's Hill and Swinyard Hill.* (*See pp. 139–140.*)



[Scale: $4\frac{1}{2}$ inches = 1 mile.]

Fig. 2.—*Section across the Herefordshire Beacon and Tinker's Hill.* (*See p. 142.*)

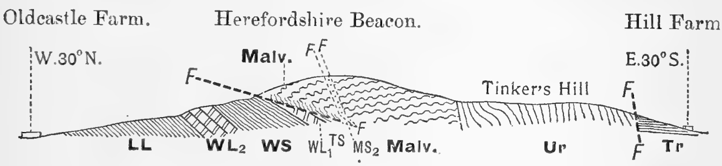
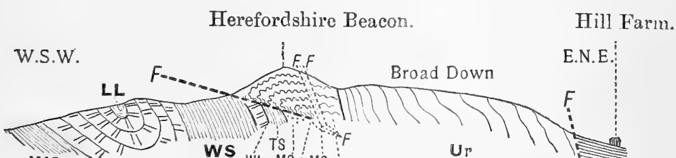


Fig. 3.—*Section across the Herefordshire Beacon and Broad Down.* (*See p. 142.*)



[Scale of figs. 2 & 3: 3 inches = 1 mile.]

Tr = Trias.
LL = Lower Ludlow Shales.
WL_2 = Wenlock Limestone.
WS = Wenlock Shale.
WL_1 = Woolhope Limestone.
TS = Tarannon Shale.

MS_2 = Upper part of May Hill Sandstone.
Ur = Uriconian.
Malv = Malvernian.
FF = Faults.

chistose, but on the road south of Clutter's Cave schistose beds dip east-north-eastward to north-eastward at 25° to 30°; in the road east of Allfield Coppice they dip eastward, and at Wind's Point the direction of dip is prevailingly the same. It should be noted

that all these instances occur close to the western boundary of the Archæan massif, and that the foliation appears to show a definite relation to the direction of this boundary.

The behaviour of the Silurian rocks on the west of this boundary is interesting. As already pointed out (p. 139), the May Hill Sandstone of the 'Silurian Pass' dips north-eastward: that is, directly towards the Archæan mass of Hangman's Hill. Near Walm's Well the Silurian rocks exhibit a tendency to curve round, and to conform to the outline of the Beacon; that they are inverted is shown by the Woolhope Limestone, which, as observed by Phillips, dips eastward at 40°.[1] Farther north-west the Malvernian rocks are in contact with the Wenlock Shale; this is exposed in a stream west of Wind's Point, where it shows an inverted dip of about 30°. The Woolhope Limestone may be obscurely traced by débris from a point south-east of this in a north-easterly direction; the May Hill Sandstone also sets in again close to Wind's Point, but can be traced by débris only. As on the southern side of the Beacon, the Silurian strata tend to conform to the outline of the Archæan mass. These relations are seen in the accompanying map (Pl. VIII), which agrees closely with that published by Phillips and by the Geological Survey.

The Wenlock Limestone, forming the peculiar curve west of Walm's Well mapped by Holl,[2] may be traced in a general northerly direction for the whole length of the Herefordshire Beacon. All along the line it has an inverted dip. It is apparently reduced in thickness towards the middle of this part of its course. On the west may be seen the Lower Ludlow Shales, exposed at the entrance-lodge of Eastnor Park, where they are about vertical; in the main road, a little to the north-west, they have an inverted dip of 63°. A fine exposure is seen down a lane leading from the east towards Oldcastle Farm, where the shales have an inverted dip varying between 50° and 58°.

The Aymestry Limestone appears to be cut out by a fault in the neighbourhood of Oldcastle Farm. This runs along a marked depression separating the normally dipping Aymestry Limestone and Ludlow Beds south of Oldcastle Farm from the inverted Lower Ludlow Shales on the east.

The curving round of the Silurian strata, the inverted dips, and the disappearance of the May Hill Sandstone, Woolhope Limestone, and part of the Wenlock Shale may be best explained, I think, on the supposition of overfolding culminating in the overthrust of the Malvernian Series on to the Silurians. The actual junction, it is true, is nowhere exposed, but its course across the contour-lines from Walm's Well to Wind's Point, which can be fixed within narrow limits, agrees with the supposition that one is dealing here with a plane-fault, or thrust-plane, having a low easterly dip. (See figs. 2 & 3, p. 141.).

The tendency of the Archæan rocks to show a schistosity with

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 71.

[2] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 73.

a definite relation to such a plane confirms this hypothesis. If the fault is not a plane-fault its dip may be greater. South of Walm's Well this thrust-plane appears to have been affected by other faults. It should be observed that Holl also considered the western boundary of the Archæan mass of the Herefordshire Beacon as a fault, marking the upheaval of the rocks of the Beacon.[1]

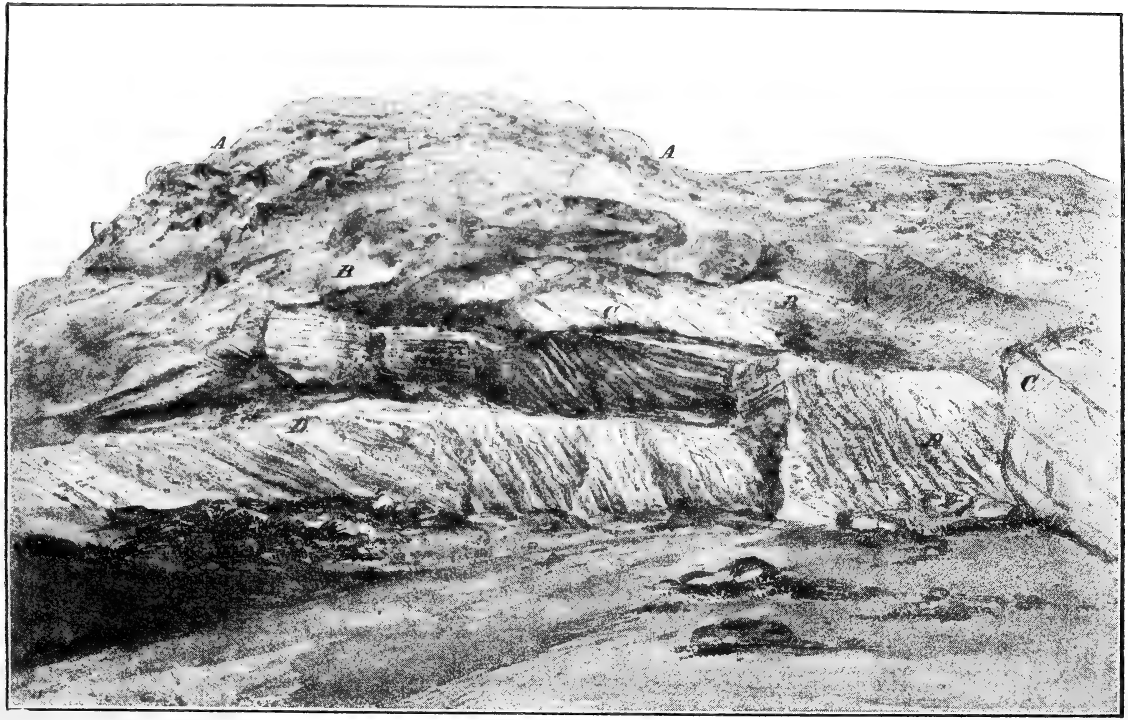
A very remarkable feature in connexion with the Herefordshire Beacon is the occurrence of fossiliferous débris of May Hill Sandstone at a number of places high up the hill. The spots where such sandstones have been found are indicated by crosses (×) on the accompanying map (Pl. VIII). This circumstance was noted by Phillips,[2] who says 'a singular occurrence of loose, fossiliferous Caradoc sandstones, high up the Beacon Hill, was met with.' This is all the more remarkable because of the inversion of the Silurian strata, and the presumed concealment of the May Hill Beds beneath the Archæan rocks of the hill. There are no elevated patches of May Hill Sandstone in the neighbourhood from which these fragments could have been derived. The latter are found in the highest trench of the Camp, around the actual summit of the hill, at a height of about 1100 feet, a height attained by no May Hill Sandstone-mass in the Malvern or Abberley districts.

It is difficult to explain these facts without the assumption that the May Hill rocks occur in place at various parts of the hill. I have searched carefully, but have found no trace of this sandstone *in situ* except at one spot, on the road from Wind's Point to the new reservoir. Its occurrence here was noted by Symonds,[3] who says:—'From the pass of the Wind's Point another fossiliferous mass of these [May Hill] strata was removed by Mr. Johnson, from the roadside opposite the little inn.'[4] Obscure traces only of this patch are left, and its relation to the Archæan is difficult to make out, but the present appearances suggest the existence of a lenticular slip of May Hill Sandstone in the Archæan Series.

Such patches on the Herefordshire Beacon may have originally been quite disconnected, or may have formed part of a general covering. Such a general covering again may have been due to original deposition of the May Hill Beds upon the Archæan, or to subsequent movements. Against the hypothesis of direct deposition are the facts mentioned in my previous communication,[5] namely, that in the Southern Malverns the May Hill Beds rest directly, and apparently without marked discordance of dip, upon the Tremadoc Slates, exhibiting no indications of an overlap towards the Malvern axis. There is every reason to believe, indeed, that the Cambrian Series passed right over the Southern Malverns, for these beds are found in the great axial infold of Raggedstone and Mid-

[1] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 96.
[2] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 62
[3] 'Old Stones' 2nd ed. (1884) p. 47.
[4] Now known as the Camp Hotel.
[5] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 166 *et seqq.*

Fig. 4.—*Former quarry at Wind's Point.* (*See p. 146.*)



AA = Syenite; *BB* = Syenitic detritus; *CC* = Purple Caradoc; *DD* = Fossiliferous Caradoc sandstone and shales.

summer Hills. The Silurian rocks west of the Herefordshire Beacon show no evidence of marginal conditions, such as we might expect if the various strata overlapped against a steep shore in the manner suggested by Holl.[1] It is probable, therefore, that the close association of May Hill Beds with the Archæan of the Herefordshire Beacon is due to movements subsequent to the deposition of the Silurian Series. This is in harmony with the view already expressed, that the Archæan of the Herefordshire Beacon has been thrust on to the Silurian; moreover, evidence will be given later (p. 160) tending to show that the May Hill Beds of the Northern Malverns have not been deposited directly upon the Archæan.

A more or less extensive covering of May Hill Beds might conceivably have been given to the Malvernian Series of the Beacon Hill by deep infolding accompanied by overthrust of the Warren House Rocks, the sandstone in that case representing the attenuated middle part of a fold. Against this view must be set the circumstance that pieces of the sandstone are far from common along the line of junction between the Malvernian and Uriconian Series. From the analogy of other districts in the Range the more probable explanation would seem to be that the May Hill Beds are present in the form of slips embedded in the Malvernian massif, like those of the Southern Malverns, Malvern Tunnel, and North Hill (see pp. 147, 149, 151), such slips marking the remnant of an infold; as such they are represented in figs. 2 & 3, p. 141.

It is certainly remarkable, on this hypothesis, that no traces of rocks other than the May Hill Sandstone occur abundantly on the Beacon. I have sought diligently for fragments of the Cambrian Quartzite or Hollybush Sandstone on the hill, but without success. Further exposures and detailed mapping of the Archæan Series on a large scale may hereafter throw light on this question, and possibly may establish the existence of one or more thrust-planes traversing the Archæan massif itself.

IV. The Depression between the Herefordshire Beacon and Black Hill.

This deep hollow is evidently marked by one or more lines of faulting, for the schists of the two hills differ markedly in strike (see Map, Pl. VIII). One of these faults was recognized by Holl,[2] and again by Mr. Rutley.[3] Prof. Hughes also speaks of 'a system of faults running through by Wind's Point.'[4] One of these, running along a deep depression, appears to bring the Uriconian of Tinker's Hill against the Malvernian of Black Hill. Two more faults, the precise location of which is difficult, seem necessary to explain the presence of a mass of May Hill Sandstone occupying the western portion of the hollow. This patch is shown in Phillips's sketch-

[1] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 100. [2] *Ibid.* p. 96.
[3] *Ibid.* vol. xliii (1887) p. 486. [4] *Ibid.* vol. liv (1898) p. 563.

map of the Herefordshire Beacon.[1] It is no longer exposed, but numerous fossils may be collected from the débris. During the laying of the foundation of the house at Black Hill, close to the Camp Hotel, and at one time occupied by Jenny Lind, the May Hill Beds were finely exposed. They are mentioned by Symonds,[2] and, as he states, there is in the collection of the Malvern Field Naturalists' Club a good water-colour sketch of the section, made by Mrs. Walter Burrow. The accompanying figure (fig. 4, p. 144) is a reproduction of a photograph of this drawing, which, owing to the kindness of Mr. H. D. Acland, the present writer was allowed o prepare.

The view is evidently taken from the south-east, the sandstone, according to Holl, dipping north-eastward. It is therefore, in all probability, inverted, like the Silurian strata immediately to the west. Both grey and purple beds were exposed, but unfortunately the relations between the two were never described. The purple beds *C*, in the middle of the figure, appear to be separated from the grey beds *D* either by an horizontal thrust-plane, or more probably by a transverse fault approximately parallel to the plane of the paper. The relation of the purple beds on the right-hand side of the picture to the beds *D* again is obscure, for it does not seem clear from the sketch whether they are separated by an irregular reversed fault with a small hade, or by a second transverse fault parallel to the face of the beds *D*. The perspective appears rather to favour the second of these hypotheses. It would seem probable that a slip of grey May Hill Beds, bounded by two parallel faults running in a general north-easterly direction, has been carried less far south-westward than the two slips of purple sandstone which bound it. Simple depression of the middle slip would suffice to produce this result.

The fossils which I have collected from the débris of this patch (M 349)[3] include:—*Lindstrœmia* sp., *Stricklandinia* sp., crinoids, etc. Fragments of a fossiliferous limestone (M 354, accidentally omitted from the map) were found near the bottom of the hollow. These, perhaps, have been derived from calcareous bands in the May Hill Series.

V. Black Hill.

This small hill is constituted by an Archæan mass, the schistose layers of which dip north-north-eastward. The mass appears to have been carried in a westerly direction to a greater degree than the Archæan on the north and south, from which it is separated by a pair of transverse dislocations. The southernmost of these, to which allusion has been made on a preceding page, does not seem to have dislocated the Woolhope Limestone. This limestone (like the May

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 84.
[2] 'Old Stones' 2nd ed. (1884) p. 47.
[3] This and similar numbers preceded by M refer to the Map (Pl. VIII) and to labelled specimens.

Hill Sandstone) is, however, not exposed, and can be traced only by the steep slope and by scattered bits of the rock; but farther north-west the Wenlock Limestone is dislocated by a transverse fault. The transverse fault north of Black Hill, recognized by Holl [1] and by Mr. Rutley [2] (the latter of whom believes that it crosses the whole width of the Archæan ridge), dislocates both the Woolhope and Wenlock Limestones. Between the two faults which cross it the Wenlock Limestone has for the most part a normal dip, but towards the south it becomes inverted.

VI. The Range between Black Hill and the Wyche.

The geology of this part of the range is comparatively simple. The Archæan mass shows a plagioclinal structure, and is evidently in contact for the whole of its length with the upper beds of the May Hill Sandstone, although this formation is rarely exposed. The junction between the two is well-defined in most places by the character of the slope. The débris of May Hill Sandstone cease precisely where the slope becomes suddenly steeper. The May Hill Beds were reached in laying the foundations of a large house, east of Perry Croft Coppice, where, as I am informed by Mr. Bennett, of Malvern, the sandstone is reversed. The same sandstone may be seen near the house called Linden (east of Colwall Station), where it rests upon the Woolhope Limestone at an angle of 83°.

The Woolhope Limestone may be traced from Herring's Coppice northward through Brand Green to near Linden, where it is interrupted by a fault, but it is nowhere sufficiently exposed to show the dip. This fault was regarded by Phillips as a sharp flexure accompanied by squeezing out of the beds,[3] but was more correctly mapped by Holl as a true fault with a little bending of the two ends. In traversing all the Silurian beds as well as the Old Red Sandstone, it brings the upper part of the Wenlock Shale (with bands of limestone), as Holl states, *loc. supra cit.* (and not the Lower Ludlow Shales, as Symonds thought [4]), against the Old Red Sandstone near the mouth of the tunnel. The fault, although somewhat irregular, is about vertical. The fossils collected from the shales include the following:—

Favosites gothlandica, Linn. (small specimens; very abundant).
F. fibrosa (?) Goldf.
Monticulipora (?) spp. (abundant).
Plasmophora petaliformis, Lonsd. (very abundant).
Heliolites interstincta, Wahl.
Syringopora bifurcata, Lonsd.
Palæocyclus rugosus, M.-Edw. & Haime (very abundant).
P. Fletcheri, M.-Edw. & Haime.
Cyathophyllum cylindricum (?) Lonsd.

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[1] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 96.
[2] *Ibid.* vol. xliii (1887) map facing p. 488.
[3] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 136.
[4] 'Old Stones' 2nd ed. (1884) p. 69.

Cyathophyllum spp.
Aulacophyllum mitratum (?) His.
Thecia Swindernana, Goldf.
Orthis (*Dalmanella*) *elegantula*, Dalm. (abundant).
O. (*Rhipidomela*) *hybrida*, Sow.
O. rustica, Sow.
Strophomena antiquata, Sow.
Str. imbrex, Pander.
Str. (*Leptæna*) *rhomboidalis*, Wilck. (abundant).
Str. (*Strophonella*) *funiculata*, M'Coy.
Leptæna (*Plectambonites*) *transversalis*, Dalm.
Pentamerus (*Barrandella*) *linguifer*, Sow. (abundant).
P. (*Siebertella*) *galeatus*, Dalm. (fairly abundant).
Rhynchonella deflexa, Sow. (very abundant).
Rh. nucula (?) Sow.
Atrypa reticularis, Linn. (very abundant).
A. imbricata, Sow. (very abundant).
Spirifera plicatella, Dalm.
Sp. crispa, His. (abundant).
Cyrtia exporrecta, Wahl.
Retzia (?) Barrandii, Dav. (abundant).
Meristella Circe (?) Barr.
Orthoceras angulatum, His.
Phacops caudatus, Brünn.
Ph. Downingiæ, Murch.
Encrinurus punctatus, Brünn.
Echinoencrinus armatus, Forbes.
Crinoidea.
Gasteropoda: three species.

The beds on either side of the fault do not strike parallel with the latter, as they should if Phillips's supposition were correct. The Wenlock Limestone, which in the southern part of its course has a normal dip, becomes inverted on the south side of the fault.

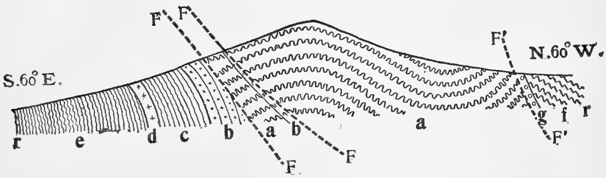
Of three other faults described by Holl as affecting the Silurian beds near Linden,[1] I have been able to detect only the northernmost. This evidently runs down a deep depression which starts at a marked indentation in the Archæan massif. Mr. Rutley represents it as crossing the ridge to a point near Malvern Wells.[2] This fault, together with the last-mentioned, detaches a strip of Woolhope Limestone, the dip of which appears to be normal; while the same limestone to the north, as far as and beyond the Wyche, is inverted. This latter portion of its course is traversed by a third fault which, running down a small valley, also affects the Wenlock Limestone. The Wenlock Limestone between this fault and that which crosses the railway has a normal dip.

A considerable thickness of shales was met with in the Malvern Tunnel. These were regarded by Symonds & Lambert as representing both the Lower Ludlow and Wenlock Shales, separated by a representative of the Wenlock Limestone.[3] This limestone is described by Symonds as nearly horizontal,[4] but an appearance of horizontality would result if the limestone dipped in the same direction as the shales at the mouth of the tunnel, and I suspect that such is the case. The authors above quoted give no measurement of this limestone, but it is evidently thin; moreover, from the general disposition of the rocks of the area, I see no reason for believing that the Wenlock Limestone is present at all in the tunnel. The bed so termed is, in all likelihood, a calcareous band in the Wenlock Shale. Holl is probably correct in mapping the whole of the beds to which allusion has been made as Wenlock Shale.[5]

[1] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 96.
[2] *Ibid.* vol. xliii (1887) map facing p. 488.
[3] *Ibid.* vol. xvii (1861) p. 155.
[4] 'Old Stones' 2nd ed. (1884) p. 60.
[5] Quart. Journ. Geol. Soc. vol. xxi (1865) map facing p. 72.

The junction of the May Hill Sandstone with the Archæan massif is evidently a thrust-plane, as I have endeavoured to show in a previous communication.[1] The tunnel-section is reproduced in fig. 5, below. Elsewhere between the Herefordshire Beacon and the Wyche there is no evidence to show the nature of the fault.

Fig. 5.—*Section of the range along the line of the Malvern Tunnel.*



[Scale: 4½ inches=1 mile.]

g = Breccia.
f = Trias.
e = Wenlock Shale.
d = Woolhope Limestone.
c = Tarannon Shales.
b = May Hill Sandstone.

a = Archæan.
rr = Railway-level.
F′ F′ = Fault between Trias and Archæan.
FF = Faults.

An interesting feature about the Wyche Pass is the occurrence of a patch of May Hill Sandstone close to the western opening of the cutting. According to Phillips, this is embedded in the crystalline rocks. The sandstone, I am informed by Mr. Wickham, of Colwall, was lately revealed in excavations made by the Malvern Field Naturalists' Club. A figure is given[2] by Phillips, showing the beds almost vertical (inverted at the top); they belong to the upper part of the May Hill Series, and a list of fossils tabulated by Phillips includes the following:—*Stricklandinia lens*, *Atrypa reticularis*, *Orthis testudinaria*, *Rhynchonella decemplicata*, *Spirifera crispa*, *Pleurotomaria fissicarina*, *Euomphalus corndensis*, *Favosites*, '*Petraia*,' etc. This patch is apparently of the same nature as those already described in the Raggedstone and Midsummer Hills,[3] and as those which will be described on a subsequent page in speaking of North Hill (p. 152).

VII. The Worcestershire Beacon and North Hill.

The fine elevations of the Worcestershire Beacon and North Hill together form one of the most conspicuous and characteristic portions of the Malvern Range. As in the middle portion of the Range, the Archæan massif is bounded on the west by May Hill Beds; but, whereas along most of the Range the May Hill Beds in contact with the Archæan belong to the upper, light-coloured part of the

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 150.
[2] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 64.
[3] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 142 *et seqq.*

formation, north of the Worcestershire Beacon the lower purple and conglomeratic part appears in force in this position, as was long ago noted by Phillips.[1] This is shown in the Map (Pl. VIII), where it may be seen how the various beds must successively abut against the somewhat sinuous western margin of the Archæan massif. Such relations have been regarded by Holl as due to overlap of the Silurian Series, but there is little to be said in favour of this view. The junction is exposed only at one point, namely, at the bottom of the 'Dingle,' a transverse depression between the Worcestershire Beacon and the Sugar Loaf, the south-western elevation of North Hill. Here the plane of junction, like the May Hill Beds themselves, is nearly vertical, as stated by Phillips.[2] The latter are, however, much crushed; and in describing the area of Cowleigh Park (p. 157) evidence will be offered tending strongly to confirm the view that the western boundary of North Hill is a fault. The schistose layers of the Archæan in the Dingle dip east-north-eastward at 70°: the strike of the folia accordingly agrees with that of the sandstone.

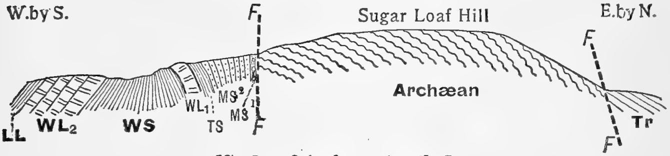
Although the eastern limit of the May Hill formation is in general easily traceable, the beds themselves are not often exposed. At Wychcrest, north of Upper Wych, there is a good exposure, now railed in by Mr. Canning to preserve the section; the grey and purplish sandstones here are inverted. The same may be said of similar beds seen in front of a new house a little farther north, and I am informed by Mr. Bennett, of Malvern, that still farther in this direction recent excavations made during the laying down of drain-pipes revealed the sandstones dipping eastward at a high angle. Other excavations made in a yard immediately south of the school, near the Vicarage at West Malvern, showed grey sandstones and sandy shales dipping westward at an average angle of about 30°: but I was inclined to suspect from the appearance of the section here that the beds had been turned over through an angle of 120°, and were thus more than completely inverted, like those of Barrel Hill Farm, in the Abberley district (p. 167). In a garden close to the quarry north of St. Edward's Orphanage, purple and grey micaceous sandstones are seen vertical; the same may be said of purple sandstones in the garden of a house on the main road, a short distance south-west of the point last mentioned. A well 65 feet deep has been sunk in these beds. Similar sandstones, with purple grits and conglomerates, have been brought up from a well (M 455) made during the present year at a point to the north-east. These beds yielded to Mr. H. D. Acland and myself abundant specimens of a fine *Lingula*, of an apparently new species.

At Rock Cottage purple sandstones and pink grits are seen in an inverted position. Farther north, however, in a field near the Lamb Inn, pink May Hill Grits have a normal dip of 40° to the west by south. At a point north of Birches Farm the upper grey sandstones also dip west-south-westward. The above-mentioned

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 60. [2] *Ibid.* p. 67.

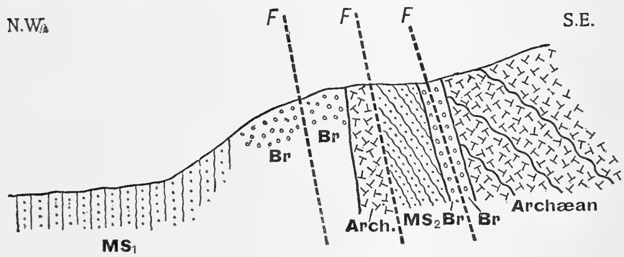
appear to be the only localities along the Worcestershire Beacon and North Hill where the May Hill Beds are not either vertical or inverted.

Fig. 6.—*Section across the Malvern Range immediately north of the Dingle.* *(See p. 150.)*



[Scale: 3 inches=1 mile.]

Fig. 7.—*Section in the old quarry north of St. Edward's Orphanage, West Malvern.* *(See p. 152.)*



[Length of section=about 35 yards.]

Tr=Trias.
LL=Lower Ludlow Shale.
WL_2=Wenlock Limestone.
WS=Wenlock Shale.
WL_1=Woolhope Limestone.
TS=Tarannon Shale.
MS_2=Upper beds of May Hill Sandstone.
MS_1=Lower beds of May Hill Sandstone.
Br=Loose breccia and rubble.
FF=Faults.

The Woolhope Limestone may be readily traced northward from Upper Wych, below Wychcrest, and the Spa; beyond this it takes a more north-north-westerly course. Whenever seen, as far north as West Malvern, it is inverted, but at Birches Farm and for a short distance to the north and south it assumes a normal dip, though it becomes again inverted as it follows the western margin of High Wood. When inverted, the limestone and associated shales form a rather steep slope, but when the dip is normal the slope is much more gradual. The Wenlock Limestone, on the other hand, has a normal dip throughout its course to the west of the hills under consideration (see Map, Pl. VIII). A peculiarity here, noted also in several other instances, is that the maximum inversion of the beds is seen, not close to, but at a little distance from the Archæan massif.

The Silurian rocks immediately west of the Worcestershire Beacon and North Hill have few and slight transverse dislocations. The only conspicuous fault is one which dislocates the Woolhope Limestone west of the Dingle: this fault is shown in Holl's map.[1] Mr. Rutley represents it as continued up the Dingle across the Archæan rocks.[2] A curious circumstance in this connexion is the occurrence of débris of May Hill Sandstone some little way up this depression, as though May Hill Beds had been squeezed into an open cleft. Prof. Hughes informs me that he has noted the same fact. The fault, however, does not dislocate the main western boundary-fault of the Archæan massif at this point, a circumstance which suggests that the former fault affords an instance of movement along an old line of dislocation.

North Hill affords a couple of interesting cases of what appear to be thrusts within the Archæan massif itself. These are seen close to the main western thrust, of which possibly they are branches. One of these thrusts is exposed in a quarry north of St. Edward's Orphanage. The relations seen are represented in the accompanying section (fig. 7, p. 151).

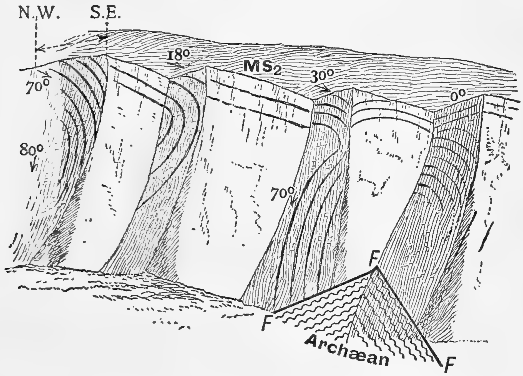
On the eastern side are Archæan rocks, the folia of which dip south by east at about 70°; these are separated from a slip of crushed, grey, shaly May Hill Sandstone by a loose breccia, evidently marking a fault-plane. The fault dips south-eastward; the sandstone-beds, perhaps about 4 yards in thickness, also dip south-eastward at 60°. West of this is seen a slip of Archæan rock not markedly foliated, from 2 to 5 yards broad, and partly covered by detritus, which also conceals the main fault on the western side of the slip. Immediately west of this detritus sandstone is again seen, followed in the neighbouring garden by the vertical purple grits to which reference was made on p. 150; these strike approximately north-north-east. Farther down the slope is seen the inverted Woolhope Limestone. It may be noted that the foliation of the Archæan rocks tends towards parallelism with the thrust-plane and with the dip of the sandstones.

A most interesting section was formerly to be seen in a small quarry close to the eastern side of the upper road, at a point about due north-east of the Lamb Inn.[3] On the south-eastern side of the quarry greenish micaceous May Hill Sandstones, apparently belonging to the upper part of the formation, strike 15° east of north; the prevailing dip is towards the western side, at angles varying from 60° to 80°; but at the top of the quarry the sandstones bend over, so as to dip in the opposite direction, at angles commonly ranging between 70° and 0°, the beds towards the south-western end of the quarry being horizontal. The axis of the fold appears to

[1] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 95.
[2] *Ibid.* vol. xliii (1887) map facing p. 488.
[3] This quarry, seen by Mr. H. D. Acland and the writer, has now unfortunately been used as a building-site, for a house named 'Valley View.' The rocks have been almost entirely concealed within the last few months.

strike about north-north-east. The accompanying diagram (fig. 8) represents the appearance that the quarry would assume if the south-eastern side were cut into a series of steps successively retreating south-eastward as the observer passed south-westward.

Fig. 8.—*Diagram showing the structure of the small quarry near the Lamb Inn, West Malvern.*

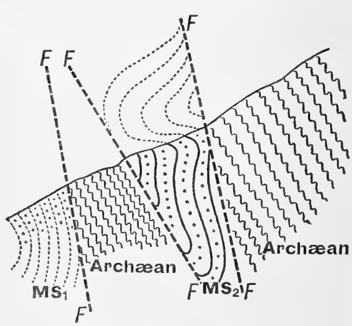


MS_2 = Upper beds of May Hill Sandstone.
FF = Fault.

At a short distance to the south-east beyond the quarry the Archæan comes in, but it is not exposed here. Judging from the character of the slope, the junction of this with the sandstone occurs at about the level of the hedge of the small field in which the quarry was situated. Towards the north-west a strip of Archæan comes in: this is seen in the road, and also in the quarry itself. The actual junction is seen to be a fault, striking north 3° west, and dipping at about 60° into the hill. The Archæan rocks in the quarry show traces of a rude foliation, the folia dipping nearly due east at about 60°.

Farther westward the purple May Hill Sandstones set in, as proved by the débris thrown out from a well sunk in a garden immediately above the lower road. Traces of the grey sandstones may be detected in the soil a little farther north, along a prolongation of the fault seen

Fig. 9. — *Diagrammatic section through the small quarry near the Lamb Inn, West Malvern.*

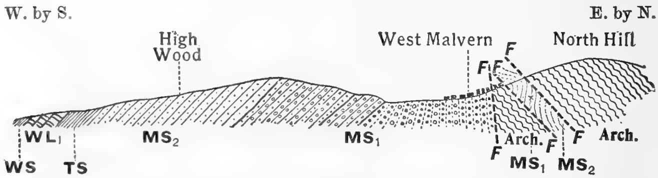


MS_2 = Upper beds of May Hill Sandstone.
MS_1 = Lower beds of May Hill Sandstone.
FF = Faults.

in the quarry. The fault and the strip of sandstone must run approximately parallel to the western boundary of the Archæan massif in this locality. It is difficult to say precisely how the relations just described have been brought about. Fig. 9 (p. 153) is an attempt to explain the phenomena observed on the hypothesis of three parallel faults, two of which are thrust-planes. Possibly all three faults are parts of a fold of the main western fault.

In fig. 10 the probable relations of this part of the Malvern Hills to the area immediately on the west are shown.

Fig. 10.—*Section across North Hill and High Wood.*



[Scale: 6 inches = 1 mile.]

WS = Wenlock Shale.	MS_2 = Upper beds of May Hill Sandstone.
WL_1 = Woolhope Limestone.	MS_1 = Lower beds of May Hill Sandstone.
TS = Tarannon Shale.	Arch = Archæan. *FF* = Faults.

A point of some interest in connexion with the geology of North Hill is the former occurrence of a patch of Haffield Breccia ('Permian') on the north-eastern slope. It was apparently first observed by Murchison,[1] and also seen by Symonds[2] 'in the great quarries on the northern flank of the North Hill,' but the precise position of the deposit was not indicated, and I have been unable to find any trace of it.

A somewhat remarkable example of Drift at West Malvern may be recorded here. The materials brought up from a well sunk last year to a depth of about 50 feet, at the spot marked 339 on the Map (Pl. VIII), immediately below the 800-foot contour-line, consisted chiefly of purple May Hill Grit, May Hill Sandstone, and much loose sandy material, together with large pieces of grey quartzose May Hill Conglomerate, well rolled by stream-action. A large Wenlock-Limestone coral (now in the possession of Mr. H. D. Acland) accompanied these. The May Hill fragments were such as might have been derived from the immediate neighbourhood, but the

[1] 'Silurian System,' 1839, p. 52, where he says:—'... The red sandy and conglomerated beds are, however, visible in one or two spots, at and near Great Malvern, on the upper side of the main road, adhering to the steep slopes of the syenite.' He mentions, a line or two lower down, that the beds dip 35° east-south-eastward.

[2] 'Records of the Rocks,' 1872, p. 415.

coral has apparently been transported across the site of the valley of Whippets Brook, presumably at a time when the latter stood at a higher level, and when the Wenlock-Limestone escarpment was loftier. In the same connexion may be mentioned the occurrence of pieces of rolled pisolitic Wenlock Limestone (M 350) far up the slope of North Hill, east of St. Edward's Orphanage, at a height of perhaps 960 feet.

VIII. The Abberley Range.

The Malvern Hills end suddenly on the north, owing to the meeting of the faults which form the eastern and western boundaries of the massif. Starting from a point near the termination is a second chain of heights, which have been collectively termed by Phillips the Abberley Hills. That author has given a valuable, but brief, description of the Range, and I would propose on the present occasion to supplement his account by the detailed description of certain portions of special interest.

The Abberley Range, beginning in Cowleigh Park, runs north-north-westward as far as Knightwick; beyond this point it takes a northerly course to Abberley Hill, where it makes a sharp bend to the east, and then gradually curves round north-westward.

It follows from Phillips's description[1] that the Range is characterized by a series of normal folds and overfolds, and by transverse faults. Mr. Wickham King has, moreover, recognized the existence of thrust-planes in the northern portion of the district.[2] The chief direction of movement in the greater part of the Range has been from the east, but in the north overfolding has taken place from the south.

As a rule, no strata older than the Silurian are exposed, but at several spots Archæan and Cambrian rocks make their appearance.

IX. The District of Cowleigh Park and Rough Hill.

The small district immediately north-north-west of North Hill is of complex structure and of great interest, although the rocks are somewhat imperfectly exposed.

The May Hill Beds of West Malvern bend round in Cowleigh Park, and at the same time become again inverted, together with the associated Tarannon Shales, Woolhope Limestone, and Wenlock Shale. One of the most conspicuous strata of the May Hill Series is a thick grit or conglomerate, commonly pink, but sometimes greenish. This occurs towards the top of the lower or purple part of the May Hill Group, and forms a well-marked band in the district of North Malvern, Cowleigh Park, and Rough Hill. It may be traced from near the Lamb Inn, through Cowleigh Park, where it appears as a marked ridge, to Rough Hill, a

[1] Mem. Geol. Surv. vol. ii (1848) pt. i.
[2] Proc. Geol. Assoc. vol. xv (1898) p. 425.

prominent part of which it forms, and is last seen east of Hill Farm. It is overlain by a not very thick series of purple and greenish sandstones and conglomerates, with grey sandstones in the upper part. These conglomerates sometimes abound in fossils; they constitute the beds known as 'Miss Phillips's Conglomerate,' and form a useful horizon in the series. They may be traced from Rough Hill, through Cowleigh Park, and have long been known in the southern part of West Malvern, where they come into direct contact with the Archæan. Traces of the purple-and-green rock may be seen still farther south. Mr. H. D. Acland informs me that he has found fragments at Hillside; while Symonds[1] speaks of alternating purple and grey beds at Wychcrest, records *Stricklandinia* from this spot, and terms the beds containing this fossil the '*Stricklandinia*-beds.' Allusion has also been made to the purple beds near Wind's Point (p. 146). I have not succeeded in convincing myself that these '*Stricklandinia*-beds' form a definite horizon, for I have found the fossil both in the lower and upper portion of the purple beds, and in the passage-beds between these and the overlying grey series, and Mr. Wickham informs me that it occurs high up in the latter beds, a short distance below the Woolhope Limestone. *Stricklandinia* is, however, perhaps, most abundant in the upper part of the purple beds, and in the passage-beds between these and the grey series. The Archæan rocks along much of the Malvern Range appear to be frequently in contact with the beds of this horizon.

In Cowleigh Park the May Hill Beds and Woolhope Limestone are both inverted.

Of considerable interest is the occurrence in this district of small patches of Archæan rock, associated in one case with Cambrian quartzite. These were observed and correctly mapped by Phillips,[2] but in Holl's map[3] one of them is incorrectly represented as extending as far north as the boundary of the Trias.

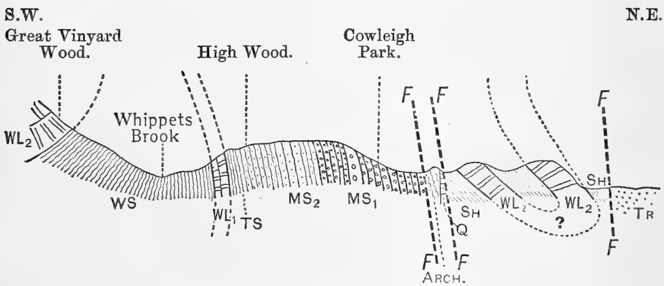
On p. 37 of Phillips's memoir, a section across the southernmost of these patches is given. The brown May Hill Sandstones immediately to the west were in 1848 evidently much better exposed than at present, and are stated to have generally a dip of 80° or more, but close to the 'syenite' to be somewhat inverted. The 'reddened drift' drawn in the depression of the 'syenite,' which Phillips was disposed to regard as Haffield Breccia ('Permian'), is, I feel sure, nothing more than débris from the adjacent purple May Hill Grits: it contains no traces of the pebbles which are characteristic of the Breccia.

The two northern exposures of Archæan rock occur in a line with that just described, and the long axis of each mass follows the same line. There can be little doubt that this is a line of dislocation, as, indeed, Holl represents it in his map (*op. jam cit.*); but the fault

[1] 'Old Stones' 2nd ed. (1884) p. 46.
[2] Mem. Geol. Surv. vol. ii (1848) pt. i, pp. 36 *et seqq.* & pl. i.
[3] Quart. Journ. Geol. Soc. vol. xxi (1865) map facing p. 72.

is not continuous with that on the eastern face of North Hill, as depicted in Holl's map. We may suppose that the Archæan rocks in Cowleigh Park have been thrust on to the inverted May Hill Beds, in much the same way as the Archæan has been thrust on to various members of the Silurian along the Malvern Range; but in the present case the overthrust and overfolding have taken place

Fig. 11.—*Section across Cowleigh Park and High Wood.*



[Horizontal scale: 3 inches = 1 mile.]

Tr = Trias.	MS_2 = Upper beds of May Hill Sandstone.
Sh = Wenlock or Lower Ludlow Shale.	MS_1 = Lower beds of May Hill Sandstone.
WL_2 = Wenlock Limestone.	Q = Cambrian quartzite.
WS = Wenlock Shale.	Arch = Archæan.
WL_1 = Woolhope Limestone.	*FF* = Faults.
TS = Tarannon Shale.	

from the north-east (fig. 11). If the direction of the fault be continued south-eastward it will meet the Archæan of North Hill immediately south of an old well sunk many years ago near the foot of the slope. The strata met with in this well (see fig. 12, p. 158) were examined by Mr. (now the Rev.) G. E. Mackie.[1] The section is tabulated as follows, in descending order:—

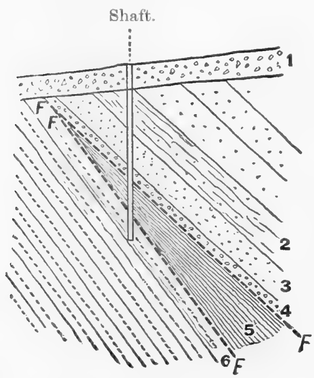
	Feet.
1. Surface-gravel (hill-débris)	12
2. Red crumbling marl with small pebbles	24
3. Coarse grey-and-red sandstone and conglomerate	16
4. Very hard breccia of quartz-pebbles in a red-and-yellow matrix	6
5. Black Cambrian Shales with *Olenus*, *Conocoryphe*, *Lingulella*, etc.	9

A boring carried 22 feet below the bottom of the well passed through 9 feet more of the Black Shales, and then through 13 feet of red rocks, apparently a repetition of beds 2 & 3. The rocks dipped at an angle of 50° (direction of dip not stated).

[1] 'Midland Naturalist,' vol. x (1887) p. 197.

Specimens of 3, 4, & 5 are still to be seen in the collection of the Malvern Field Naturalists' Club, and owing to the kindness of Mr. H. D. Acland and of Mr. W. Edwards, the Curator, I have been able to examine them. The Black Shale is indistinguishable from that seen near White-leaved Oak in the Southern Malverns, but no fossils are visible in the specimens preserved. The fossils, I understand from Mr. Mackie, were sent to Cambridge. It is hoped that a precise determination of the species may in the future show whether they belong to the zone of *Sphærophthalmus*, or to some other zone, not represented in the Southern Malverns. No. 4 is a greenish grit, essentially resembling portions of the lower part of the May Hill Sandstone: it contains numerous, rather large, angular and rounded quartz-pebbles up to a couple of inches or more in diameter. These resemble the pebbles that occur in the conglomeratic May Hill and Cambrian beds of the district, and differ from the sedimentary Cambrian quartzite. No. 3 consists chiefly of purple and greenish grit, containing angular or partly rounded fragments of quartz, felsite, and other rocks, the largest of which measured about an inch across. One side of the specimen is composed of light green material resembling one of the green, fine-grained, sandy bands alternating with some of the purple May Hill Sandstones and Grits. I have no hesitation in referring Nos. 3 & 4 to the lower, or purple, part of the May Hill Sandstone, and presumably No. 2 will come into the same category.

Fig. 12.—*Theoretical section of a shaft at West Malvern.*



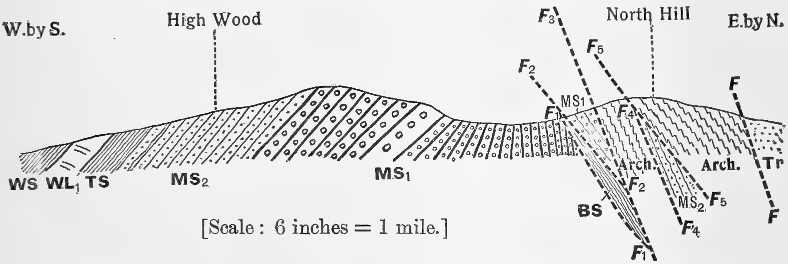
[Scale: 1 inch = 100 feet.]

1 = Hill-débris. *FF* = Faults.
2, 3, 4 = May Hill Sandstone.
5 = Black Shales.
6 = May Hill Sandstone.

The occurrence beneath the Black Shales of beds similar to Nos. 2 & 3 is very striking and suggestive, and can be hardly explained except on the hypothesis that the original relative positions of the Black Shales and lower sandstones have been reversed. Originally the latter may have rested on the former, being now simply inverted; but in all probability the Black Shales have been thrust on to the sandstone (see fig. 12). The thrust may well be the same as that which has brought the Archæan rocks of Cowleigh Park on to the purple May Hill Sandstones. With the object of testing this hypothesis I endeavoured to ascertain by enquiry the direction of the dip of the beds in the well, and was informed by Prof. Hughes that the Black Shales dipped north-eastward, precisely the direction required by the hypothesis; were no such thrust-plane present, one might expect

the dip to be easterly. I also understood that Prof. Hughes had already concluded that the dislocation in the well was the same as that bringing up the Archæan rocks of Cowleigh Park. The supposed mutual relations of the various rocks of the northern part of West Malvern are shown in fig. 13.

Fig. 13.—*Section across High Wood and North Hill.*



[Scale: 6 inches = 1 mile.]

Tr = Trias.
WS = Wenlock Shale.
WL_1 = Woolhope Limestone.
TS = Tarannon Shale.
MS_2 = Upper beds of May Hill Sandstone.
MS_1 = Lower beds of May Hill Sandstone.
BS = Black Shales.
Arch = Archæan.
FF = Faults.

The structure of the portion of Cowleigh Park and North Malvern north-east of the fault affords further evidence in favour of the same view; but the area is imperfectly exposed, and consequently has been misunderstood, and to a certain extent incorrectly described and mapped.[1] The beds here also are evidently in part inverted, the overfolding having taken place from the north-east (see fig. 11, p. 157). A limestone, regarded by Phillips as Woolhope Limestone, and so represented in the Geological Survey map, is clearly the Wenlock Limestone. My friend, Mr. Wickham, who has a close acquaintance with the Silurian of the Malvern district, and has made a special examination of this rock at my request, states that it 'is evidently the Wenlock Limestone, as seen by the nodules, the crinoid-joints, and particularly by the absence of the rusty appearance, so characteristic of the Woolhope Limestone around Malvern.' It may be traced from Mill Coppice in a southerly direction towards Cowleigh Park Farm, dipping westward; soon, however, it sweeps completely round, and for a short distance runs parallel to its former course, almost touching the road. Nevertheless, this limb of the fold has a dip similar to that of the other. Shales may be seen both above and below the limestone; the Lower Ludlow and Wenlock Shales are accordingly both represented here. The shales occupying the concavity of the fold are exposed just

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, pp. 37 & 75 & Sheet 55 S.E.

beneath the limestone at a point north-north-west of Cowleigh Park Farm; the others are well shown on the road north-west of the farm, where they were seen by Phillips.[1] They dip northward. Regarded by Phillips as the base of the Wenlock Shale, they yielded only a few imperfect fossils.[2] In view of this dearth of fossils, it appears difficult at present to say whether these beds represent the base of the Lower Ludlow Shale or the summit of the Wenlock Shale. Mr. Wickham regards them as Wenlock: in this case the fold would be a syncline, as represented in the section (fig. 11, p. 157).

Judging by the character of the soil, the Wenlock and Ludlow beds are bounded on the north by a transverse fault running along the depression occupied by Whippets Brook. It would appear also from the character of the soil, and from fragments turned up by the plough, that a small patch of purple sandstone, let into the Wenlock beds, forms the eastern boundary of the middle Archæan patch, but no exposure is seen.

Of the rocks now exposed on the eastern side of the southernmost of the Archæan patches, the nearest to the latter is a shattered rock, which Phillips regarded as altered 'Caradoc' (May Hill Sandstone), though he correctly termed it a 'quartzite, or quartz-rock.' This resembles no May Hill rock in the district; on the other hand, it is both macroscopically and microscopically identical with the Cambrian quartzite of the Southern Malverns and of other parts of the Midlands, and I have no hesitation in ascribing to it the same age, in spite of the fact that it has hitherto afforded no fossils.[3] Phillips figures this quartzite as resting on the 'syenite,' but does not state in the text that such is the case: the relations were probably inferred. The rock being now imperfectly exposed, its dip cannot be determined; moreover, its junction with the Archæan is not visible; for the present, therefore, it must remain doubtful whether the two rocks are separated by a fault, or not.

Still farther east are seen brown May Hill Sandstones. These are separated from the Wenlock and Ludlow beds by a transverse fault, evidently noticed by Phillips, and represented in his section, but no longer exposed. The brown sandstones contain, as Phillips states (*loc. supra cit.*), numerous fucoids. Traces of May Hill Sandstone are seen as far east as Cowleigh Park Farm.

The structure shown is perhaps best explained on the hypothesis of the overthrust of the Archæan rocks on to the overfolded May Hill Sandstone, followed by the faulting down of overfolded beds to the north-east (fig. 11, p. 157). The same hypothesis may account for the position of the upper set of purple sandstones in the well at

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 37.

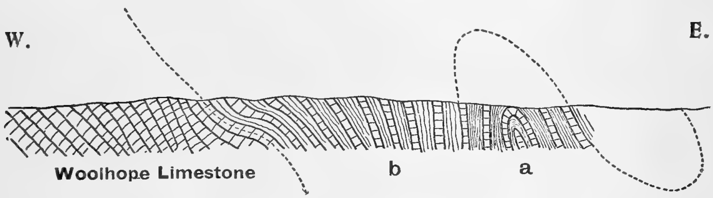
[2] Namely, *Phacops caudatus (?)*, *Orthis elegantula (?)*, *Rhynchonella* sp., and crinoids.

[3] Prof. Lapworth informs me that he recognized this Cambrian quartzite some years ago.

West Malvern (fig. 12, p. 158); for Prof. Hughes informs me that the dip of the breccia appeared to be steeper than that of the Black Shales, a circumstance which suggests that the junction of the two beds is a fault. (Figs. 12 & 13, pp. 158 & 159.)

The northern termination of the thrust-plane cannot be made out, owing to the lack of exposures. The fault evidently continues north of Whippets Brook, undisturbed by the transverse dislocation there, and possibly passes along the eastern side of Rough Hill, unless indeed, as seems likely, it is cut out by an ordinary fault letting down the purple beds on the east of that hill. One of the faults seen on each side of the Archæan in fig. 11 (p. 157) is doubtless continued northward, and probably terminates against a transverse fault running south of Hill Farm. The beds of Rough Hill are inverted, as seen in the road at the southern end of the hill. Here a subordinate overfold affects the Tarannon Shales (fig. 14).

Fig. 14.—*Section along the road south of Rough Hill.*



[Length of section = about 50 yards.]

b = Grey shales, with bands of limestone } Tarannon Shales.
a = Purple shales, with bands of limestone }

Immediately south of this road, the Silurian rocks of Rough Hill are separated from those of Cowleigh Park by a transverse fault which displaces the Woolhope Limestone a little towards the west, on the northern side of the fault. This fault is apparently a continuation of that inferred to the east of the two northerly Archæan patches, and still follows the brook. The Woolhope Limestone may be traced northward along the western flank of North Hill towards Hill Farm, south of which it terminates against a transverse fault bringing the grey May Hill Beds against both the purple and grey May Hill Beds, and the Woolhope Limestone of Rough Hill. North-west of Rough Hill the Woolhope Limestone, inverted at Whippets Brook, assumes a normal dip. On the eastern side of Rough Hill brown May Hill Sandstones dip about due east-north-east. These beds probably occupy a position east of the fault on the eastern side of the hill, and perhaps correspond to the similarly situated brown beds seen east of the quartzite in Cowleigh Park.

North of Whippets is found a patch of breccia, as to the nature of which Phillips was in doubt.[1] This is clearly the 'Haffield Breccia,' as can be seen by the character of the fragments: it appears to rest directly upon the purple May Hill Beds.

The district of Hill Farm, Doddenham Grove, and Crumpton Hill is geologically a gentle anticline of Upper May Hill Beds and Woolhope Limestone, as may be seen from the outcrops and dips in the Map (Pl. VIII). This is bounded on the south chiefly by the fault to which allusion has been already made (p. 161), and partly by a second fault meeting the former at an angle, and causing the Woolhope Limestone to terminate abruptly in a field west of Rough Hill. The last-mentioned fault may possibly extend farther north than represented in the map, as there is a clearly-marked depression running in this direction, exactly in the line of the fault.

South of Norrest Farm the Wenlock Limestone is faulted against the Wenlock Shale. Small patches of Coal Measures may be seen north-west and south of New Inn.

It will now be convenient to summarize the chief points of interest in the geology of Rough Hill, Cowleigh Park, and the adjacent part of West Malvern.

The structure may be explained on the hypothesis of overfolding from the north-east of the Silurian and Cambrian Series, accompanied by overthrust of the Cambrian and Archæan rocks on to the Silurian, and by subsequent faulting-down north-eastward of an overfold, along a line coinciding in direction with the old thrust. North-westward the overfolding gives place to ordinary folding, the district on the north exhibiting a gentle syncline. These movements were complicated by transverse faulting, apparently of earlier date than the great post-Liassic faulting which affected the district on the east.

The occurrence of both Lower and Upper Cambrian beneath the May Hill Beds is of much importance: firstly, as showing the northerly extension of the Cambrian, and secondly, as indicating that the May Hill Beds do not rest directly upon the Archæan, but are brought into contact with it by means of faults. It is evident, from a consideration of the Map (Pl. VIII) and from the description of the geology of North Hill, that the thrust-plane of Cowleigh Park does not affect the Archæan rocks of that hill; for, apart from the fact that there is not the smallest indication of a fault crossing the ridge at this point, the relations between the Archæan and the May Hill Beds described on pp. 152 & 158 make it clear that overthrusts from the east-south-east have taken place, and that the strip of May Hill Sandstone introduced into the Archæan Series by the movements which preceded or accompanied the overthrust is continuous along a line crossing that of the Cowleigh Park thrust. This shows that the latter terminates against the Archæan of North Hill, and affords an interesting and fairly conclusive proof: (1) that the Cowleigh Park

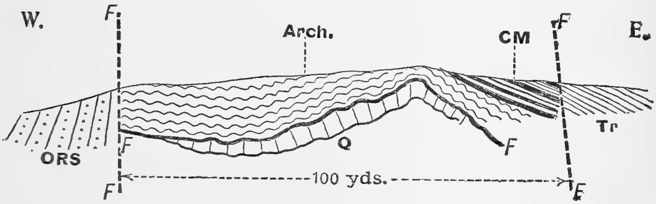
[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 112.

thrust is of earlier date than the movement which raised the Archæan of North Hill; and (2) that the May Hill Beds west of this mass were not deposited directly against it, but owe their present juxtaposition to faulting, for they had already undergone faulting, overfolding, and overthrust before the uplift of the Malverns. These considerations afford, perhaps, the most satisfactory disproof of the overlap of the Silurian Series against the Malvern Range.

X. The Patch of Archæan and Cambrian near Martley.

The existence of this patch (M 378) was known to Murchison[1] and Phillips.[2] During the past year notes on the locality have appeared by Mr. C. St. A. Coles,[3] Dr. Callaway,[4] and myself.[5] The Old Red Sandstone and Coal Measures seen by Phillips are no longer visible. Fig. 15 has been made by combining the two sections drawn by Phillips and myself, and introducing the main fault which bounds the Palæozoic on the east.

Fig. 15.—*Section across the Archæan patch near Martley.*



Tr = Trias.	Q = Cambrian Quartzite.
CM = Coal Measures.	Arch = Archæan.
ORS = Old Red Sandstone.	*FF* = Faults.

The Archæan rocks have been apparently thrust on to the Cambrian quartzite, the base of the former having undergone shearing parallel to the thrust-plane. The overthrust series has been subsequently folded along a north-and-south axis, together with the Old Red Sandstone. This secondary folding has been accompanied by upthrust of the Archæan and Cambrian. The Coal Measures were subsequently deposited unconformably on the faulted and folded series, and in later times the old rocks covered by the Trias were let down on the eastern side. We appear to have in this small area an epitome of the history of the Malvern and Abberley Ranges.

[1] 'Silurian System,' 1839, pp. 420, 421.
[2] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 38.
[3] Geol. Mag. 1898, p. 304.
[4] *Ibid.* p. 379.
[5] *Ibid.* p. 562.

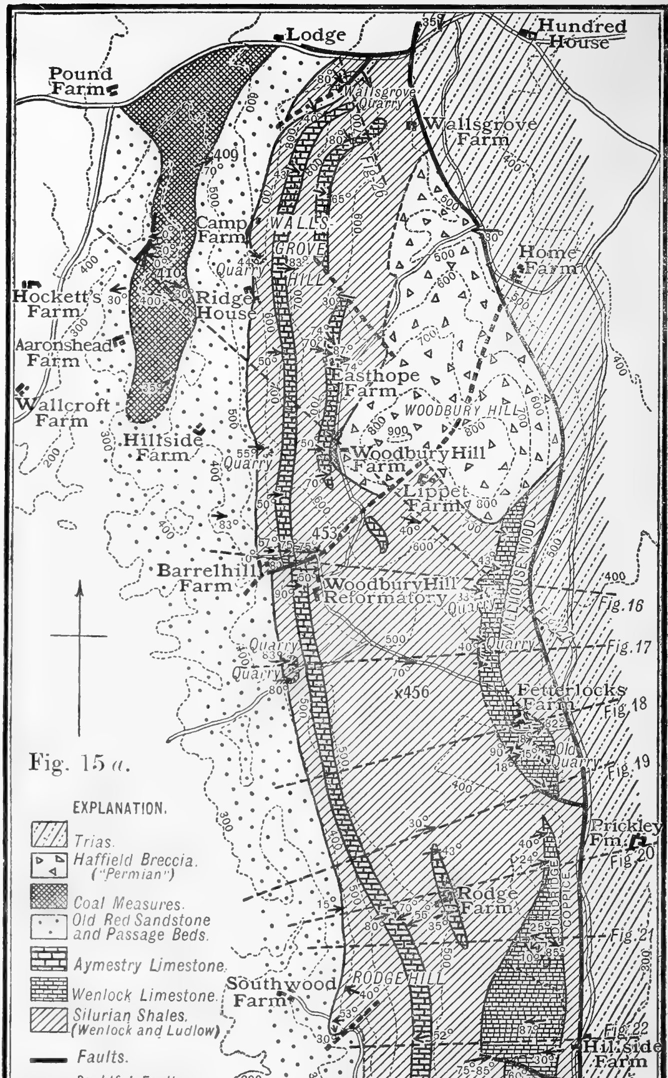


Fig. 15 *a.*

Geological Map of
WOODBURY, WALLSGROVE, PENNY & RODGE HILLS,
and of the Adjacent Portion of the
Forest of Wyre Coalfield.

XI. Woodbury, Wallsgrove, Rodge, and Penny Hills.

(See Map, fig. 15 *a*, p. 164.)

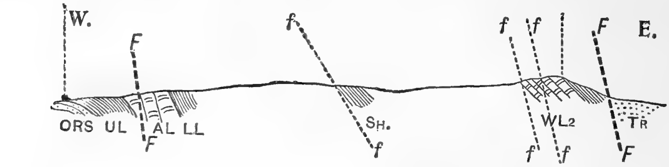
The present writer, having carefully investigated the mutual relations between the various formations in the Malvern and adjacent districts, had concluded from these investigations, and from the data given by Phillips, that the Range probably dated from one of two periods. The Haffield Breccia itself, or occasionally certain underlying Coal Measures, rest unconformably and relatively undisturbed on the overfolded series. The movement which produced the Range must, therefore, have taken place before the deposition of these particular Coal Measures. On the other hand, it follows from Phillips's description of the Malvern and Abberley Ranges, from confirmatory statements by Mr. Cantrill,[1] and from further evidence which I propose to give, that the overfolded series includes beds ranging up as high as the Lower Old Red Sandstone. The Range, therefore, arose during some part of the Old Red Sandstone or Carboniferous periods. Now, there is some reason to believe that during these periods two chief tectonic movements took place in the Western Midlands—the first probably in the interval between the deposition of the Lower and Upper Old Red Sandstone, and the second between the deposition of the Middle and Upper Coal Measures; proofs of the latter movement have been given by Mr. D. Jones in the case of the Forest-of-Wyre Coalfield.[2] I accordingly made a careful survey of some of the northern hills of the Abberley Range and of the adjoining part of the Forest-of-Wyre Coalfield, with the object of determining whether any portion of the Coal Measures shared in the overfolding. The structure of the hills will be dealt with first.

Woodbury Hill is formed of a mass of Haffield Breccia, generally resting, as Phillips maintains, directly and unconformably upon the Silurian, but sometimes separated from the latter by a feeble representative of the Coal Measures.[3] Murchison states that the coal-beds on the western slopes of Woodbury Hill consist 'merely of thin shreds of Carboniferous strata thown up in elevated positions, or rather squeezed up in separate patches between the trap[4] and the Silurian rocks. These poor and shallow deposits were necessarily soon exhausted, and no accurate records of the works remain.'[5] Phillips (*loc. cit.*) states that the 'cap of peculiar conglomerate.... discloses, between it and the Silurian strata, a narrow, very distinct outcrop of coal and coal-shales.' These Coal Measures are no longer visible, but I observed traces of them in the form of bits of Coal-Measure sandstone, clay, and coal at Woodbury Hill Farm. Bedding

[1] 'Geol. of Wyre Forest Coalfield' Kidderminster, 1895, p. 10.
[2] Trans. Fed. Inst. M.E. vol. vii (1894) p. 287.
[3] Mem. Geol. Surv. vol. ii (1848) pt. i, pp. 152 & 153.
[4] Murchison's 'trap' is the Haffield Breccia.
[5] 'Silurian System,' 1839, p. 135.

can be very rarely detected in the breccia; but it is clear, from the way in which the base tends to follow the contour-lines, that it rests, as Phillips states, on the Silurian beds as a cap, the base of which as a whole is gently inclined. The Coal Measures, too, from their

Fig. 16.—*Section from Wallhouse Wood to Barrel Hill Farm.*



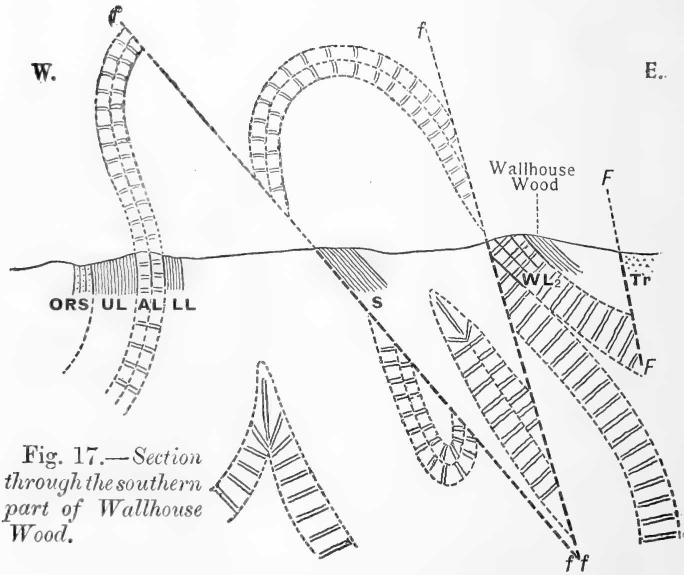


Fig. 17.—*Section through the southern part of Wallhouse Wood.*

[Scale of figs. 16 & 17: 4 inches = 1 mile.]

ORS = Old Red Sandstone and Passage-beds.
UL = Upper Ludlow Shales.
AL = Aymestry Limestone.
LL = Lower Ludlow Shales.
WL_2 = Wenlock Limestone.
Tr = Trias.
S = Shales of doubtful age.
FF = Faults.
ff = Hypothetical faults.

position, must have a gentle dip, very different from that of the underlying Silurian beds. The disturbances mentioned by Murchison must be such as a soft yielding stratum would undergo when squeezed between two more massive and rigid formations. The

Coal Measures of Woodbury Hill, therefore, rest with striking unconformity upon the Silurian beds.

The Silurian of the hills under immediate consideration includes beds ranging from the Wenlock Shale to the Downton Sandstone and Ledbury Shale. The latter are followed by the Lower Old Red Sandstone, to which there is every reason to believe that they are truly conformable. On the west the series is thrown into a narrow overfold of Aymestry Limestone and Ludlow Shales, the axis of which dips eastward, as shown by Phillips.[1] Denudation of this fold has resulted in the formation of a double line of outcrop of the limestone, as seen in Wallsgrove Hill and Rodge Hill. The more westerly outcrop can be traced continuously from a point west of Wallsgrove Farm to the extreme southern end of Rodge Hill. Except in the highest parts of Rodge Hill, this band is inverted, dipping, with the immediately underlying and overlying shales, eastward at angles varying from 40° to 90°; in the northern part of this course the dips vary from 40° to 57° (see fig. 27, p. 174); in the southern part, with one exception (50°), the dip varies from 75° to 90° (see figs. 16–24). West of Rodge Farm the Aymestry Limestone and Lower Ludlow Shale dip at 70° and 55° respectively westward (see fig. 20, p. 169); and south-south-west of the same farm the limestone has also a normal dip of 52° (see fig. 22, p. 169). The Upper Ludlow rocks west of the limestone, wherever seen, have similar dips. West-south-west of Southwood Farm, the western limit of the Upper Ludlow Shales is dislocated by a transverse fault, the exact location of which is difficult. This fault is represented by Phillips (*op. cit.* pl. ii), and also in the Geological Survey maps, as crossing the whole breadth of the Silurian tract; but I have been unable to trace it beyond the Upper Ludlow Beds of Rodge Hill. It seems to have resulted from a short, sharp, transverse flexure in the Upper Ludlow Shales and Downton Sandstone, as represented in the map (fig. 15 *a*, p. 164). The Downton Sandstone south of the fold is much contorted and shattered. West of Rodge Farm the overfolding of the upper beds is considerable, the Downton Sandstone dipping into the hill at an angle of 15°, and overlying the normally superjacent red Ledbury Shales (see fig. 16, p. 166). At Barrel Hill Farm, beds which are apparently the red Ledbury Shales are completely inverted, and underlie the Upper Ludlow Shales, the Downton Sandstone being squeezed or faulted out.

The eastern band of Aymestry Limestone has the peculiarity of being squeezed or drawn out for longer or shorter distances, or perhaps in some places overthrust by the shales to the east. Wherever the dip can be taken it is, with one exception, easterly. Five nearly or quite disconnected portions of the limestone may be seen: a very short strip crops out immediately west of Wallsgrove Farm; a longer one on the south-west; and a still longer strip west of Woodbury Hill. Immediately north of Easthope Farm the limestone shows a subordinate overfold, the axis of which dips westward.

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 151.

The shales both above and below the limestone at Easthope Farm dip from 72° to 74° eastward ; at Woodbury Hill Farm the limestone dips 50° in the same direction (see fig. 27, p. 174), and just to the

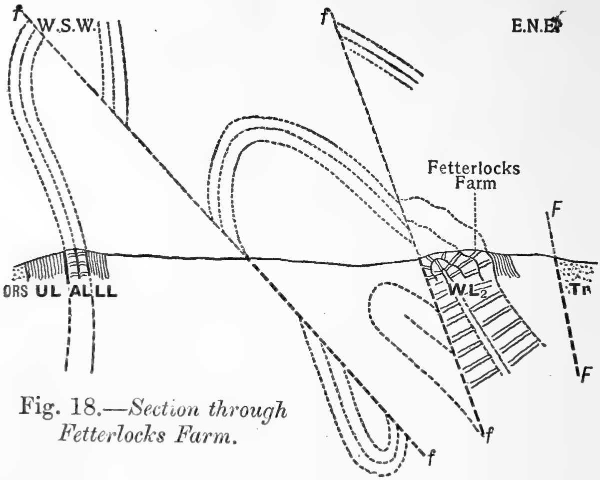


Fig. 18.—*Section through Fetterlocks Farm.*

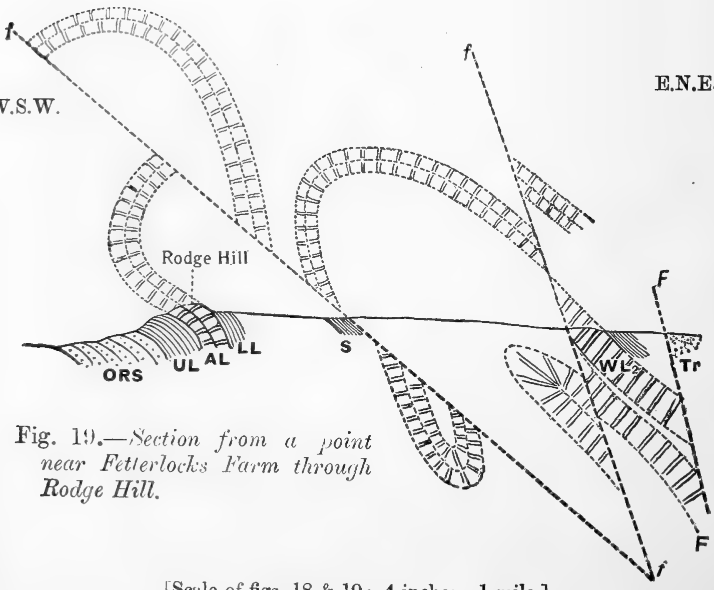
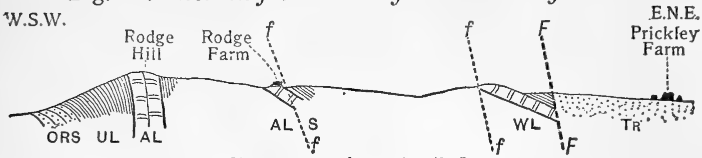


Fig. 19.—*Section from a point near Fetterlocks Farm through Rodge Hill.*

[Scale of figs. 18 & 19: 4 inches=1 mile.]

south the immediately overlying shales dip 70° east by north. At the northern end of the strip the shales immediately west of the limestone dip west by north at 30°. South of Woodbury Hill Farm

Fig. 20.—*Section from Prickley Farm to Rodge Hill.*



[Scale: 4 inches = 1 mile.]

Fig. 21.—*Section through Dundridge Coppice and Rodge Hill.*

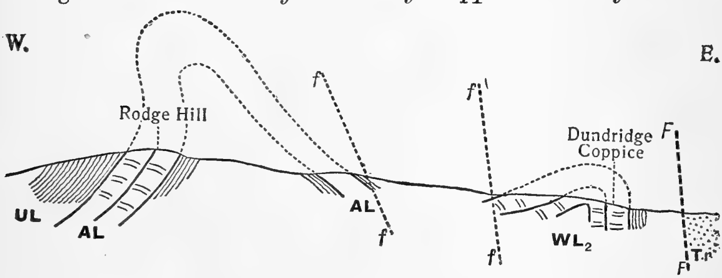


Fig. 22.—*Section through Hillside Farm and Rodge Hill.*

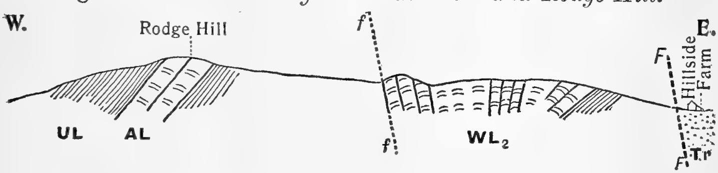


Fig. 23.—*Section from Penny Hill to Rodge Hill.*

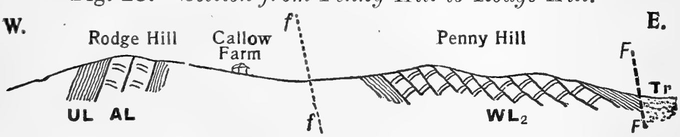
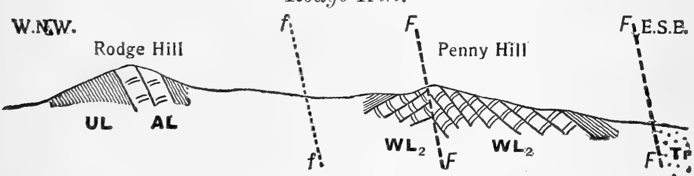


Fig. 24.—*Section through the southern ends of Penny Hill and Rodge Hill.*



[Scales of figs. 21–24 = 6 inches to the mile.]

ORS = Old Red Sandstone and Passage-beds.
UL = Upper Ludlow Shales.
AL = Aymestry Limestone.
WL_2 = Wenlock Limestone.

Tr = Trias.
S = Shales of doubtful age.
FF = Faults.
ff = Hypothetical faults.

the limestone seems to disappear, but reappears for a short distance south of the little transverse valley which runs north of Woodbury Hill Reformatory. South of this point the limestone again disappears for a considerable space, and is not seen again until Rodge Farm is reached, where it has a normal dip of 35° (see fig. 20, p. 169). A little north of the farm hard shales are seen, dipping east-north-eastward at 30° to 43° (see fig. 19, p. 168). They appear to be the shales either immediately underlying or overlying the limestone, but the few fossils obtained from them were insufficient to decide this point; in the absence of the limestone they form a small escarpment facing west. South of the farm the limestone finally disappears.

The shales between the two bands of Aymestry Limestone are presumably everywhere of Lower Ludlow age. They are seen only near Easthope Farm and Woodbury Hill Reformatory; in both places they include thin bands of limestone. In the last-named locality the following fossils were collected:—

Strophomena rhomboidalis, Lindström.
Str. funiculata, M'Coy.
Orthis lunata, Sow. (?).
Rhynchonella sp.
Pentamerus sp.
Lingula lata, Sow. (?).
Crania implicata, Sow.
Phacops caudatus, Brünn.
Beyrichia Wilkensiana, Jones (?).
Mytilus mytilimeris, Conr.
Favosites fibrosa, Goldf.
Ptilodictya scalpellum, Lonsd.
Crinoidea.

The Upper Ludlow Shales are well exposed at a number of points on the western slopes of Wallsgrove Hill and Rodge Hill, where many of the characteristic fossils may be collected. The direction of dip appears always to agree with that of the limestone near, as may be seen from an inspection of the map (fig. 15 *a*, p. 164). East of the eastern outcrop of limestone the few exposures of shale have not, so far, yielded characteristic Upper Ludlow fossils.

The eastern side of the hills under consideration is much more difficult to interpret than the western.

The Wenlock Limestone, emerging from beneath the Haffield Breccia at the southern end of Woodbury Hill, appears to run continuously, save for a single interruption, as far south as the southern end of Penny Hill. It shows a remarkable disposition, not easy to understand. At Fetterlocks Farm (fig. 18, p. 168), and in the southern part of Dundridge Coppice (fig. 21, p. 169) the limestone forms an anticline. In the former locality this is almost isoclinal; in the latter the axis dips west. The eastern limb of this anticline shows a series of small undulations with axes passing east and west, as seen in the quarry immediately west of the Coppice. West of Hillside Farm the limestone appears to show fan-structure (fig. 22, p. 169), the beds on the eastern side being apparently inverted. In Penny Hill the beds dip eastward, those on the western side being apparently inverted (fig. 23, p. 169). The great apparent thickness seen here and near Hillside Farm is probably due to repetition by

folding or faulting.[1] Between Fetterlocks Farm and Dundridge Coppice the limestone, dipping eastward at low angles (fig. 19, p. 168), tails out. North also of this farm the outcrop is relatively narrow, except at one point, and the beds have a similar easterly dip (figs. 16 & 17, p. 166). At the south-western corner of Penny Hill a short strip of limestone is faulted against the main band (fig. 24, p. 169). The lithological characters of the rock, and the variety and abundance of the fossils, clearly show this to be the Wenlock Limestone: it dips 33° north-westward. The following fossils were obtained as the result of a short search:—

Favosites gothlandica, Linn.	*Rhynchonella borealis*, Schl.
F. fibrosa, Goldf.	*Strophomena funiculata*, M'Coy.
Heliolites interstincta, Wahl.	*Orthis elegantula*, Dalm.
Thecia Swindernana, Goldf.	*Encrinurus variolaris*, Brongn.
Halysites catenularia, Linn.	*Lichas Barrandei*, Fletcher.
Monticulipora pulchella, M.-Edw.	*Phacops Downingiæ*, Murch.
Meristella tumida, Dalm.	*Beyrichia* sp.
Atrypa reticularis, Linn.	Crinoidea, polyzoa, etc.

The disposition of the Wenlock Limestone of the area may be, perhaps, best explained on the supposition that the beds all along the line mark portions of a simple or complex anticline, the axis of which is sometimes vertical or inclined westward, but usually dips eastward; and that in places a portion of one side of the fold, and at one spot the whole, has been pinched or drawn out. It should be pointed out that this explanation is in part in agreement with that of Phillips, who attributed to the limestone a simple but broken anticlinal disposition.[2]

The shales between the outcrop of the Wenlock Limestone and the line of the eastern band of Aymestry Limestone are rarely exposed, and furnished no distinctive fossils. The spots where such shales occur are indicated by the dip-arrows in the map (fig. 15 *a*, p. 164).

A number of transverse faults complicate the structure of the district. One of these intersects the Wenlock Limestone and adjoining shales south of Hillside Farm; a second probably traverses the Wenlock Beds near Prickley Farm; a third possibly crosses the limestone of Dundridge Coppice, the beds north and south of the road showing a very different arrangement. A fourth appears necessary to account for the dislocation of the eastern band of limestone north of Easthope Farm; and a fifth runs along the road north of Wallsgrove Hill.

It will be seen from the foregoing description that the structure of the area is not altogether simple, and differs in not unimportant respects from that supposed by Phillips.[3] The anticline of Wenlock

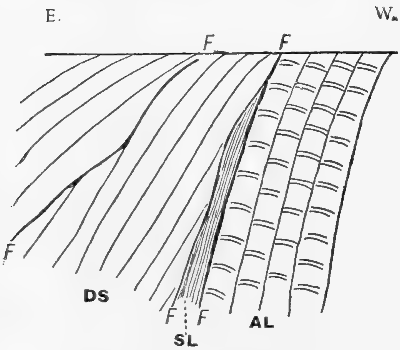
[1] The normal thickness of the Wenlock Limestone, as seen west of the Northern Malverns and Rough Hill, is between 250 and 300 feet. Phillips gives a thickness of 100 to 280 feet for the Malvern district, Mem. Geol. Surv. vol. ii (1848) pt. i, p. 78.

[2] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 152.

[3] *Ibid.* pp. 151 & 152.

Limestone has by no means the simple character ascribed to it by that author, and its axis would appear generally to have a steep slope to the east. Whatever be the disposition of the limestone, it is necessary to assume the existence of one or more faults between the outcrops of this rock and those of the Aymestry Limestone, in order to explain the non-appearance of a third line of outcrop of the latter. Phillips attempted to explain the structure of the district by the assumption of a fault traversing the middle of the shale-series, and passing between the two limestone-masses at the southern end of Penny Hill [1]; but the great apparent thickness of the shales in places, as, for instance, immediately south of Woodbury Hill, tells against this simple explanation. In all probability the district is traversed by several faults, which have resulted in bringing shales of different horizons together. The occurrence of overfolds, and the relative positions of the Aymestry and Wenlock Limestones, seem to indicate clearly that at least one of these faults is a thrust-plane, the up-throw of the fault being on the eastern side. This view is confirmed by the geological structure of the northern part of Wallsgrove Hill, now to be described. Some of the faults have been tentatively represented in figs. 16–24 (pp. 166–169), but I have not ventured to insert them in themap.

Fig. 25.—*Section seen at the southern end of Wallsgrove Quarry.*



SL = Ledbury Shale.
DS = Downton Sandstone.
AL = Aymestry Limestone.
FF = Faults.

The structure of the northern end of Wallsgrove Hill is very peculiar. Both the eastern and western bands of Aymestry Limestone curve round north-eastward, and appear to terminate; the former ends abruptly in a small rounded tump; the latter seems to tail out. In Wallsgrove Quarry the remarkable relations described by Phillips [2] are still to be seen.

The Aymestry Limestone, dipping 70° or 80° north-westward, is faulted against a reversed series of beds, including not only the Upper Ludlow Shales and Downton Sandstone (into which the former passes), but also a small thickness, perhaps 4 or 5 feet, of purple Ledbury Shale. Phillips (*loc. cit.*) attempted to explain these relations by assuming the existence of a second overfold faulted down on the east. The facts may be more simply explained, however,

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 152 & pl. ii.
[2] *Ibid.* pp. 153–154; see also Proc. Geol. Assoc. vol. xv (1898) fig. 10, p. 356.

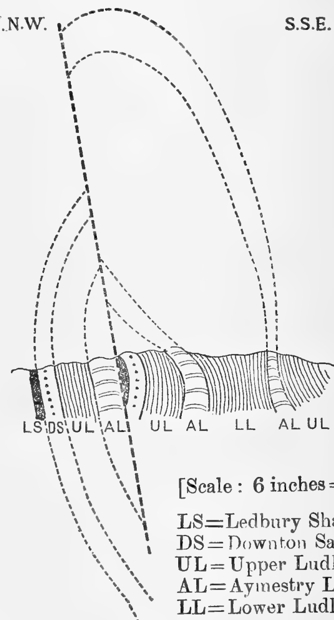
by the more probable assumption of overthrust of a portion of the overfold running all along Rodge and Wallsgrove Hills, no additional fold being thus postulated (fig. 26).

The peculiar disposition of the layers of Downton Sandstone (fig. 25, p. 172) suggests that those on the east have been successively thrust over those on the west, and the latter on to the Ledbury Shale, and this in turn on to the Aymestry Limestone. The limestone at the northern end of the quarry curves round, and evidently terminates against the thrust-plane, a circumstance which confirms the view that I have adopted. The strike of the main thrust-plane is about south-south-west, but in the southern part of the quarry it becomes more south-westerly.

The disposition of the Ludlow and Downton beds in the quarry is somewhat complicated by small transverse faults, of too insignificant a character to represent in the map (fig. 15*a*, p. 164): these would seem to terminate against the thrust-plane east of the Ledbury Shales. The Downton Sandstone in the quarry contains abundance of fucoids, *Pachytheca*, *Pterygotus*, *Lingula*, etc.

We have, then, fairly clear evidence of a well-defined thrust-plane in the Abberley Hills dipping north-westward at an angle varying from 70° to 80°.

Fig. 26.—*Section across the northern part of Wallsgrove Hill.*



[Scale: 6 inches = 1 mile.]

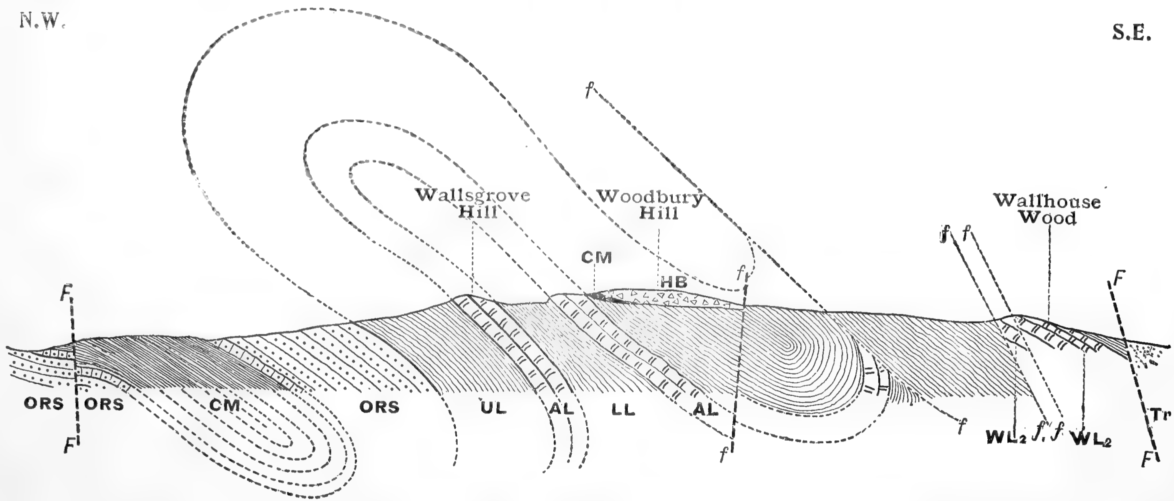
LS = Ledbury Shale.
DS = Downton Sandstone.
UL = Upper Ludlow.
AL = Aymestry Limestone.
LL = Lower Ludlow.

XII. The Old Red Sandstone and Coal Measures west of Wallsgrove Hill.

As already shown by Phillips,[1] the Old Red Sandstone in the Malvern and Abberley districts shares the folding which has affected the conformably underlying Silurian rocks; immediately west of Wallsgrove Hill it is markedly inverted, like the Ludlow

[1] Mem. Geol. Surv. vol. ii (1848) pt. i; see also T. C. Cantrill, 'Geol. of Wyre Forest Coalfield' Kidderminster, 1895, p. 10.

Fig. 27.—*Section across Woodbury and Wallsgrove Hills, and the adjacent portion of the Wyre-Forest Coalfield.*



[Scale: 4 inches = 1 mile.]

Tr=Trias.
HB=Haffield Breccia.
CM=Coal Measures.
ORS=Old Red Sandstone and Passage-beds.
UL=Upper Ludlow.

AL=Aymestry Limestone.
LL=Lower Ludlow.
WL_2=Wenlock Limestone.
FF=Faults.
f f=Hypothetical faults.

Beds of that hill. Exposures of the sandstone in this locality are not common, but the limits of the formation may be generally determined with some approach to accuracy by the character of the slope, the colour of the soil, and by débris. Allusion has been already made (p. 167) to the inversion of the Passage-beds. At a point north-west of Barrel Hill Farm the Old Red Sandstone dips 83° east by north, and in the bed of a small stream at a point north-west of Camp Farm greyish-white sandstone, such as characterizes the lower part of the Old Red Series in Herefordshire, dips 70° east by north. West of the tongue of Coal Measures protruding southward from the Forest-of-Wyre Coalfield the dips are gentler, and evidently normal in character. At a point east of Hocketts Farm, and north-north-west of Aaronshead Farm, purple and greyish-white Old Red Sandstone dips 30° west-south-westward. In the valley at a point north-east of this, along the western margin of the Coal Measures, horizontal greyish-white and red sandstones are seen; these evidently belong to the Old Red Sandstone, like those already mentioned. The bed of the stream at this point is occupied by a fault, probably of small throw: this runs in a general northerly direction. East of the fault the same grey sandstones are seen in a horizontal position. They are overlain directly by horizontal Coal Measures, the superposition being actually seen in the steep bank of the stream.

Towards the southern extremity of the tongue of Coal Measures, shales belonging to that formation dip 35° north-north-westward, and close to the eastern boundary of the tongue an important section in a hopfield west of Ridge House shows soft ferruginous sandstones and clays, with bits of coal—undoubtedly belonging to the Coal Measures—dipping 30° east-south-eastward. Still farther north, close to the inverted grey sandstone already mentioned, greatly contorted clay, overlain and underlain by clearly stratified shaly coal, may be seen on the bank of the stream. These beds are thrown into a small dome, about 5 feet across, overfolded towards the east.

The details given above show: (1) that the Coal Measures rest with apparent conformity upon certain white and red sandstones of the Old Red Series; and (2) that the strata, horizontal or inclined at low angles on the western side of the tongue, as in the Forest-of-Wyre Coalfield generally, on the eastern side become contorted and inverted, like the Silurian beds. The tongue accordingly represents a narrow synclinal fold the eastern side of which is inverted (fig. 27, p. 174). The mere shape of the tongue, with its axis parallel to that of Wallsgrove Hill, might have prepared us for this conclusion. It is clear, moreover, that the Coal Measures of Wallsgrove Hill rest unconformably, and comparatively undisturbed, upon an overfolded and overthrust series of Silurian, Old Red Sandstone, and older Coal Measures. The evidence is, therefore, fairly convincing that the great movements which resulted in the folding of the beds of Wallsgrove Hill took place chiefly during Coal-Measure times.

XIII. The Relation of the Coal Measures to Underlying Rocks in other Parts of the Malvern and Abberley Districts.

The relations of the higher Coal Measures to older rocks in the locality just described are quite in accordance with those seen in other portions of the Abberley district and south of the Malverns. As described by Phillips, a thin strip of Coal Measures, evidently corresponding with those of Woodbury Hill, crops out beneath the Haffield Breccia of Berrow Hill.[1] They rest here, with marked unconformity, upon the Old Red Sandstone: traces of the old workings are still visible, but there is no actual exposure. At Martley, too, Coal Measures appear to rest unconformably upon an overfolded and overthrust series of Archæan, Cambrian, and Old Red Sandstone (p. 163). Coal Measures are stated to have been formerly worked near Old Storridge Hill[2]; these beds, not mentioned, and evidently not seen, by Phillips, are still well-exposed in a little stream close to the New Inn, on the road between Storridge and Worcester, where they were pointed out to me by Mr. Wickham King. Their relation to the adjoining Silurian strata is not clear. The seams of the Newent Coalfield also rest directly upon the Old Red Sandstone.[3] The manner of outcrop of these measures, as shown in the Geological Survey map, appears clearly to indicate that they constitute a thin sheet having closer relations to the Keuper Breccia than to the Old Red Sandstone, the folds of which, as pointed out by Phillips (*loc. cit.*), pass underneath the former. Murchison states, moreover, that the Coal Measures could be seen formerly in open quarries resting unconformably upon the Old Red Sandstone, and that they have shared in all the flexures of the New Red Sandstone.[4] Abberley Hill itself may probably furnish hereafter confirmatory evidence. The Coal Measures immediately north of the tract of overfolded rocks constituting this hill are, it is true, no longer exposed, but in Murchison's section[5] across this hill they are represented as dipping directly towards, and in the same direction (south-east) as, the Silurian beds. Murchison expressly states, moreover, that the strata of the Forest-of-Wyre Coalfield become completely inverted as they approach the Abberley Hills. No Upper Coal Measures, however, have been detected hitherto beneath the Haffield Breccia that caps Abberley Hill.

XIV. The Unconformity at the Base of the Upper Coal Measures in Districts other than those of Malvern and Abberley.

The unconformity at the base of the Upper Coal Measures in the Abberley Hills district is the local representative of an uncon-

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 150.
[2] Murchison, 'Silurian System' 1839, p. 135.
[3] Mem. Geol. Surv. vol. ii (1848) pt. i, pp. 104 *et seqq.*
[4] 'Silurian System' 1839, p. 153.
[5] *Ibid.* pl. xxxvi, fig. 1.

formity spread over a wide area, not only in the British Isles, but also on the Continent.

In the Coalbrookdale Coalfield it has been shown by Mr. M. W. T. Scott[1] and Mr. D. Jones[2] that the Upper Coal Measures rest upon a denuded surface of older Coal Measures. South of this area the former rest directly upon the Old Red Sandstone. This relation is maintained still farther south, until at Harcott the older Coal Measures appear again between the two formations, unconformable to both.[3] In the neighbourhood of the Trimpley anticline, on the western side of the Forest-of-Wyre Coalfield, according to Mr. Cantrill, the Upper Coal Measures also rest upon older Coal Measures.[4] In the southern part of the Forest-of-Wyre Coalfield the Upper Measures again rest upon the Old Red Sandstone.[5]

In the South Staffordshire Coalfield, according to Mr. F. Meachem,[6] the Upper Coal Measures rest unconformably upon the older Coal Measures; and in the Lower Lickey district, according to Prof. Lapworth, beds which appear to be the Upper Coal Measures rest directly upon the Cambrian and Silurian rocks.[7]

In the Leicestershire Coalfield certain beds have been regarded as probably Upper Coal Measures by the Rev. W. H. Coleman[8] and Prof. Hull,[9] and supposed to rest unconformably upon older Coal Measures; but they are considered by Mr. H. T. Brown to belong to the latter series, to which they appear to be conformable.[10] The last-named observer believes that all traces of the Upper Coal Measures were removed in pre-Permian times. Mr. Gresley, however, describes a small patch of Coal Measures resting directly upon the Rawdon Fault, which traverses the older Coal Measures, and, with apparent justice, regards it as a relic of the Upper Coal Measures (Trans. Fed. Inst. Min. Eng. vol. iv, 1893, p. 431).

In Yorkshire the Rotherham Red Rock, with an associated series of Coal Measures, underlies the Permian beds unconformably, and appears to rest with marked unconformity upon the older Coal Measures.[11]

In Cumberland the Whitehaven Sandstone, with its *Spirorbis*-limestones and beds of coal, has been shown by Mr. J. D. Kendall to be markedly unconformable to the older Coal Measures; he justly regards this rock as representing the Upper Coal Measures.[12]

[1] Quart. Journ. Geol. Soc. vol. xvii (1861) p. 457.
[2] Geol. Mag. 1871, p. 200.
[3] Trans. Fed. Inst. Min. Eng. vol. vii (1894) p. 287.
[4] 'Geol. of Wyre Forest Coalfield' Kidderminster, 1895.
[5] Trans. Fed. Inst. Min. Eng. vol. vii (1894) p. 287.
[6] *Ibid.* vol. viii (1895) p. 401; see also C. De Rance, *ibid.* vol. x (1896) p. 244.
[7] Proc. Geol. Assoc. vol. xv (1898) p. 368.
[8] 'Outline of Geol. of Leicestershire' (White's 'History') 1846, p. 25.
[9] 'Geol. of Leicestershire Coalfield & of Country around Ashby-de-la-Zouch' Mem. Geol. Surv. 1860, p. 56.
[10] Quart. Journ. Geol. Soc. vol. xlv (1889) pp. 18 *et seqq.*
[11] 'Geol. of Yorks Coalfield' Mem. Geol. Surv. 1878, p. 481; and 'Geol. of Parts of Notts, Yorks, & Derby' W. T. Aveline, Mem. Geol. Surv. 2nd ed. (1880) pp. 12 & 26.
[12] Trans. Fed. Inst. Min. Eng. vol. x (1896) p. 202.

In Southern Scotland unconformity between the Upper Coal Measures with *Spirorbis* and the older Measures has been observed in the coalfields of Ayr, Dalmellington, and Sorn[1]; and in the Sanquhar Coalfield, where the Upper Coal Measures rest on faulted older Measures.[2] Unconformity between the same beds has also been inferred in Lanarkshire[3] and elsewhere.[4]

In the remaining British coalfields, so far as I am aware, no unconformity has been detected hitherto between the Upper and older Coal Measures and in certain districts where undoubted Upper Coal Measures are present, as, for example, in the Warwickshire Coalfield, the unconformity, if present at all, is apparently but slight.[5]

In the coalfields of Southern England and Wales the Coal Measures have been divided into an Upper, Middle, and Lower series; but, as Mr. Jukes-Browne points out, there is reason to doubt whether the Upper Series corresponds with the true Upper Coal Measures of Central and Northern Britain[6]; and Mr. Strahan[7] has recently expressed his conviction that the true Upper Coal Measures are absent from the South Wales Coalfield. But in Devon Mr. Somervail has recognized above the true Culm Series a group of conglomeratic beds which are apparently older than the Permian, and rest unconformably upon the Culm.[8] Further research may show that these conglomerates correspond with the Upper Coal Measures of other parts of Britain.

Sufficient evidence has now been adduced to show that the unconformity at the base of the Upper Coal Measures in the Abberley district is not merely a local phenomenon, and that considerable disturbance took place in Britain in Coal-Measure times. Similar but more convincing evidence of extensive movements during this period on the Continent has long been known. This is admirably brought out by Suess, who recognizes in Western and Central Europe several important old mountain-ranges: the Armorican, extending from Southern Ireland to the Central Plateau of France; the Variscian, running from the northern edge of the Carpathians to the same plateau; and the Iberian, extending from Galicia and Northern Portugal to the Guadalquivir in Southern Spain. These ranges all arose towards the close of the Carboniferous period,[9] and have been collectively termed the Hercynian System, a name due to Marcel Bertrand.[10] The Hercynian folding has affected all rocks ranging up to, and including portions of, the Coal Measures. The denuded and folded series is overlain by the Permian, and in places by the Upper Coal Measures. The Hercynian ranges have been subjected to later

[1] Mem. Geol. Surv. Scotl. 1869, Expl. Sheet 14, pp. 19 & 22.
[2] *Ibid.* 1871, Expl. Sheet 15, p. 33. [3] *Ibid.* 1873, Expl. Sheet 23, p. 35.
[4] *Ibid.* 1872, Expl. Sheet 22, p. 22, & *ibid.* 1879, Expl. Sheet 31, p. 32.
[5] H. H. Howell, 'Geol. of Warwickshire Coalfield' Mem. Geol. Surv. 1859.
[6] 'Building of the British Isles' 2nd ed. (1892) p. 157.
[7] Rep. Brit. Assoc. 1898 (Bristol) p. 865. [8] *Ibid.* p. 877.
[9] 'Antlitz der Erde' vol. ii (1888) pp. 104, 111, 114, 117, 124, 129, 130, 150 *et seqq.*, 165.
[10] Bull. Soc. géol. France, ser. 3, vol. xv (1887) p. 438.

movements, which have taken place in the same sense as the primary folding, but everywhere, except in the Central Plateau of France, the chief disturbance appears to have occurred in Coal-Measure times.[1]

XV. The Directions of the Hercynian Movements in the Western Midlands.

The disposition of the folds over the wide area affected by the Hercynian movement shows that the movements took place along two series of intersecting lines. Thus the Armorican and Variscian ranges meet at nearly a right angle in the Central Plateau of France. A similar series of intersecting lines is well shown in the Malvern area. The direction of the axes of the folds is somewhat variable, so much so, indeed, that Mr. Wickham King has distinguished a northerly and southerly (Malvernian), an easterly and westerly (Hercynian or Mercian), a north-westerly and south-easterly (Charnian or Woolhope), and a north-easterly and south-westerly (Scandinavian) folding.[2] Now, although these terms may be useful for descriptive purposes, they somewhat disguise, in my opinion, the true state of the case, by suggesting that the folds are of different ages, and are related in time to folds produced at other periods. The relations may be more simply explained by recognizing the existence in the Malvern and Abberley area of one set of folds running either north and south or north-west and south-east, and a second set at right angles to these respectively. The former set is characterized by the peculiarity that the overfolding has commonly taken place from the eastern side, while the latter set has been overfolded from the south. There is no reason to believe that these two sets of movements have taken place at different geological periods; for, apart from the great similarity of the structure produced in each case and the continuity of the folds,[3] the inversion of the older Coal Measures associated with both sets of folds and the unconformity at the base of the Upper Coal Measures throughout the Western Midland district go far to show that both sets of movements took place chiefly in the limited interval between the deposition of the older and the newer Coal Measures.

XVI. The Relation of the Folds of the Malvern-Abberley Area to those of Adjoining Districts.

The geological relationships between the Malvern, Woolhope, May Hill, and Tortworth areas were clearly seen by Phillips.[4] He

[1] Suess, 'Antlitz der Erde' vol. ii (1888) pp. 123 *et seqq.*, 138, 147, & 148.

[2] Proc. Geol. Assoc. vol. xv (1898) p. 426.

[3] The most striking instance of this is seen at the northern end of the Abberley Hills, where the axis veers rapidly round from its northerly direction and turns eastward. Were the two folds even of slightly different ages, it might be reasonably expected that one would continue beyond the end of the other. The two are clearly continuous.

[4] Mem. Geol. Surv. vol. ii (1848) pt. i, pp. 181, 189, 190, & 207.

pointed out that the structure of May Hill is related on one hand to that of the Malvern district and on the other to that of the Woolhope district. In the two last-named areas the axial planes of the folds dip towards the eastern side, and occasional inversions are seen in May Hill. I have observed that at Flaxley, at the southern end of this district, the Silurian beds are inverted. The dip of the beds on the eastern side of the Forest-of-Dean coal-basin is, on the whole, decidedly steeper than on the western, as may be seen from the section drawn to scale by Messrs. Insole & Bunning.[1] In some places the beds are vertical, or even slightly inverted. There is, therefore, a general tendency for the axes of the north-and-south folds in these districts to dip eastward, as in the Malvern and Abberley areas.

In addition to the north-and-south folds others occur directed transversely. Besides the great fold of Abberley Hill, there is a second which gives a westerly strike to the rocks on the northern side of the Silurian area of Ledbury, while a third gives the northern limit to the Forest-of-Dean Coalfield. The combination of the two sets of intersecting folds tends to divide the whole area into a series of basins, separated by anticlinal ridges of varying direction and breadth. The Old Red Sandstone area west of the Malvern and Abberley districts shows a series of these basins and ridges. The close relations which exist between these folds and those that form the coalfields of South Wales and Bristol make it difficult to avoid the conclusion that we are dealing with the same set of folds throughout the region to which I have referred, and that the movements which produced the Malvern and Abberley Ranges also gave rise to the coal-basins of the Forest of Dean, South Wales, and Somerset. Now, the two last-named coalfields constitute a part of Suess's great Armorican Range, which, from evidence quoted on pp. 178–79, must be regarded as chiefly of Coal-Measure age. We have, therefore, evidence from two distinct sources that the Malvern and Abberley Ranges are of Coal-Measure age, and may accordingly regard this West-of-England chain as a small branch of the great Hercynian system, mainly produced in the same limited geological interval. It will be seen, then, that there is no reason to believe that the two sets of folds which have given rise to the coal-basins of Southern Britain are of appreciably different ages, and on this point I am at issue with Prof. Hull,[2] who maintains that the folds running east and west are of earlier age (pre-Permian) than those running north and south (post-Permian).

The post-Permian age of the Pennine chain has been disputed by Edward Wilson[3] and Mr. Teall,[4] who have both maintained that the Pennine uplift took place in pre-Permian times, as did

[1] 'The Forest-of-Dean Coalfield' 1881.

[2] Rep. Brit. Assoc. 1870 (Liverpool) p. 74; Quart. Journ. Geol. Soc. vol. xxiv (1868) p. 323 & vol. xxv (1869) p. 171; 'Trias & Permian of Midlands' Mem. Geol. Surv. 1869, p. 111; 'Coalfields of Gt. Britain' 3rd ed. (1873) p. 468; *ibid.* 4th ed. (1881) p. 522; Geol. Mag. 1880, p. 185.

[3] Geol. Mag. 1879, p. 500; & *ibid.* 1880, p. 93.

[4] *Ibid.* 1880, p. 92.

also Joseph Lucas many years before.[1] The Pennine Chain has clearly been subjected to more than one movement of elevation, though the main folding occurred in pre-Permian times. It does not appear certain, however, that this latter movement took place chiefly in the interval between the Carboniferous and Permian Epochs. Reference has been made (p. 177) to the unconformity at the base of the Rotherham Red Rock with its associated series of Coal Measures. There is some reason to believe that these beds represent the Upper Coal Measures,[2] but their stratigraphical relations both to the older Coal Measures and to the Permian strata are still insufficiently known. Further researches may show that a considerable uplift of the Permian area took place in Coal-Measure times, and that the movements which threw the Coal Measures of the North of England into basins had already commenced at that period. The circumstance that in certain of the British coalfields the Upper Coal Measures rest with apparent conformity upon the Middle Coal Measures need present no insuperable obstacle to the acceptance of this hypothesis, for while other areas were being raised these districts may have been still subsiding and receiving deposits. Mr. De Rance, indeed, considers that the Lancashire Coalfield is a basin formed contemporaneously with the Coal Measures.[3]

It is necessary to remark that, while I believe that the Hercynian movement played an exceedingly important, and in places a preponderating, part in the formation of the coal-basins and of associated regions of elevation, I would by no means contend that the movements which took place in Coal-Measure times were solely responsible for the completion of these basins and ridges. It is readily admitted that in some cases movements (in the same sense as the earlier movements) which took place after the deposition of the Upper Coal Measures may have largely contributed to the final result. The Trimpley anticline on the eastern side of the Forest-of-Wyre Coalfield may be a case in point. In this interesting district, briefly described by Mr. Cantrill, the Old Red Sandstone has been folded and overfolded, together with the overlying, unconformable, older Coal Measures, and has sometimes been thrust on to the latter. The overfolding has taken place from the south-east, and the structure produced thus approaches that of Wallsgrove Hill (pp. 165 *et seqq.*). It is not clear how far the Upper Coal Measures share in the folding, and Mr. Cantrill considers that an anticline which had probably commenced to rise by the end of Middle Coal-Measure times was not completed till after the Upper Coal-Measur times, and that the movement was most active immediately after that period. At the same time he thinks it probable that the older Coal Measures in the Forest-of-Wyre district were elevated into a broad anticline ; that enormous erosion took place along a general north-easterly and south-westerly line before the deposition of the

[1] Geol. Mag. 1872, p. 338.

[2] Mem. Geol. Surv. 'Geol. of Yorks Coalfield' 1878, p. 481 ; & 'Geol. of Parts of Notts, Yorks, & Derby' 2nd ed. (1880) p. 12.

[3] Trans. Fed. Inst. Min. Eng. vol. xiii (1897) p. 301.

Upper Coal Measures; and that the Permian beds were laid down upon the latter 'with some amount of local unconformity.'[1]

We have, therefore, evidence of the continuation in a northerly direction of the Hercynian folds. Whether or not the primary movement during Coal-Measure times was more important than later movements in the Trimpley district it appears difficult at present to determine. Further investigations on the relation of the newer and older Coal Measures of the district may be expected to throw light on the subject.

XVII. The Connexion between the Upthrusts or Overthrusts of the Archæan Massif of the Malverns and the Overfolding of the Beds to the West.

A close relation is discernible in the district of the Malvern Hills between the elevation of the Archæan massif and the overfolding of the Cambrian and Silurian beds to the west. This relation is clearly brought out in the accompanying map (Pl. VIII).

It will be seen from the map that the western margin of the area, over which the beds are vertical or inverted, in most places tends to follow the western border of the Archæan, whatever may be the horizon of the beds so affected. This shows, on the one hand, that the overthrust or upthrust was to a certain extent independent of the disposition of the ordinary folds; and, on the other, that it had a close relation to the process of overfolding. It would appear that the beds were first folded, and then overfolded along an axis somewhat oblique to that of the normal folds, and that the overfolding culminated in overthrust of the Archæan massif. A noteworthy feature of this movement is the very high inclination of the fault: this in some places is nearly vertical; indeed, it is only in the Malvern Tunnel that the fault can be actually proved to be a thrust-plane having any considerable hade. The movement has been in fact, to a certain extent, a simple upthrust.

The amount of inversion of the Silurian strata in several localities diminishes towards the thrust-plane. Examples of this are seen west of North Hill, where the greatly inverted beds at a little distance from the fault, on approaching the latter, tend to become vertical (see fig. 6, p. 151). This phenomenon is apparently to be explained on the supposition that subordinate thrusts traverse the Silurian, like those affecting the passage-beds of Wallsgrove Hill (pp. 172–73), where the beds nearest the thrust-plane tend towards parallelism with it.

XVIII. The probable Evolution of the West-of-England Chain in several Sections not produced quite simultaneously.

It has been pointed out (pp. 162–63) that the overfolds and overthrusts which have affected the southern end of the Abberley Range took place before those which have elevated the bulk of the

[1] 'Geol. of Wyre Forest Coalfield' Kidderminster, 1895, pp. 34, 36.

Malvern Range; the latter, in their turn, appear to have been produced somewhat earlier than the southernmost portion, the only remnant of which is seen in Chase End Hill, for the schists of the latter appear to have overridden the Cambrian strata, the folds of which are parallel to the Archæan axis at the southern end of Raggedstone Hill. The West-of-England chain appears, therefore, to have been successively evolved in sections from north to south.

It may be noted that the two northern sections show a tendency towards convexity of the western or front margin, a circumstance frequently observed on a much larger scale in the case of great mountain-ranges. If the southern extremity of the range was originally continuous with the May Hill elevation, in the general direction of which it points, a similar tendency may have been exhibited here also, for the axis in that case running south-westward must gradually turn and unite with that of the southern part of the May Hill anticline. The Y-shaped disposition of the May Hill mass, pointed out by Phillips,[1] suggests, indeed, a former connexion between the folds of the two districts. It may be noted that a secondary production of schists from the old Archæan material appears to have taken place in the case of each of the three sections of the chain.[2]

The movement in each section of the chain probably took place in more than one stage. Thus, in the main mass of the Malvern Range the elevation appears to have commenced with gentle folding, and to have culminated in a powerful upthrust or overthrust, accompanied by overfolding (p. 182). Moreover, the thrust-planes themselves appear to have undergone secondary folding.[3] At Wallsgrove Hill, in the Abberley Range, the disposition of the passage-beds and their relation to the Aymestry Limestone suggest that the overfolding culminated in overthrust (p. 167). At Martley the overthrust rocks appear to have undergone subsequent folding and faulting (p. 163).

XIX. The Relation of the Haffield Breccia to the Underlying Formations.

It has been long recognized that the Haffield Breccia in the Malvern and Abberley districts rests with striking unconformity upon the Lower Palæozoic and Archæan rocks.[4] At certain points it is separated from these older rocks by thin strips of Coal Measures (p. 176), which must be inclined at an angle differing but little from that of the Breccia itself. The presence of Coal Measures beneath the Breccia at some points, and their absence at others, can be explained only by one or other of two hypotheses. The Breccia

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 181.

[2] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 153 & 157; Geol. Mag. 1898, p. 562; and pp. 141, 142, 163 & pl. viii of the present paper.

[3] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 154 & 155; see also p. 163 of the present paper.

[4] Mem. Geol. Surv. vol. ii (1848) pt. i, pp. 112, 113, 1[illegible]3, 161, etc.

either rests conformably upon the Coal Measures, and overlaps them at certain points; or else it lies unconformably upon, and oversteps them in places. If the hypothesis of overlap were true, it might be expected that no new Permian beds could appear elsewhere between the Breccia and Coal Measures; but, so far from the Trappoid Breccia remaining at the base of the Permian system, lower horizons appear as the beds are traced away from the Abberley district towards the north and north-east.

Thus at Warshill, according to Mr. Wickham King, the Trappoid Breccia no longer rests directly upon Coal Measures, or older rocks, as in Woodbury and Abberley Hills, but on some 70 feet of Middle Permian marls and sandstones, themselves underlain by Lower Permian marls.[1] In the Enville district a considerable thickness of sandstones, conglomerates, and marls underlies the Breccia[2]: the Middle Permian beds alone, as defined by Mr. King, increasing in thickness from 200 to 330 feet when traced towards the north-western part of the area.[3] In the Clent Hills a thickness of over 500 feet of sandstones, conglomerates, and marls intervenes between the Trappoid Breccia and the Upper Coal Measures. At West Bromwich 700 feet of red sandstones and marls overlie the Upper Coal Measures; at Sandwell Park 575 feet of sandstones and marls, and at Hamstead 1353 feet of similar rocks occupy the same horizon.[4]

There is, moreover, some positive evidence of unconformity between the 'Permian' and Upper Coal Measures. For though Mr. Cantrill regards the Wyre Forest Permians as 'Coal-Measure Passage-Beds,'[5] and considers that in some places there is conformity between them and the Upper Coal Measures, he remarks that in other places there appears to be a certain amount of break, as, for instance, in the neighbourhood of the Trimpley anticline.[6] It would appear also from the Geological Survey map, and particularly from that given by Mr. D. Jones,[7] that the Permian near Bridgenorth transgresses across the Upper Coal Measures so as to rest upon their basal beds.

It would seem fairly certain, then, that the Haffield Breccia or Trappoid Breccia of the Western Midlands rests unconformably, not only upon the Archæan, Silurian, Old Red Sandstone, and older Coal Measures, but also upon the Upper Coal Measures, where these are present. When the last-named are absent, this circumstance is due, in part at least, to denudation. Pre-Permian denudation in

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 110 & 111. I see no reason to doubt, as Mr. King has done in his paper (p. 101), the identity of the Trappoid Breccia of the Malvern and Abberley Hills with that seen at Warshill and other areas north of the Abberley district.

[2] E. Hull, 'Trias & Permian of Midlands' Mem. Geol. Surv. 1869, p. 12.

[3] Quart. Journ. Geol. Soc. vol. lv (1899) table facing p. 108.

[4] T. C. Cantrill, Quart. Journ. Geol. Soc. vol. li (1895) pp. 530–532.

[5] *Ibid.* p. 547.

[6] *Ibid.* p. 542, and 'Geol. of Wyre Forest Coalfield' Kidderminster, 1895, pp. 34 & 36.

[7] Trans. Fed. Inst. Min. Eng. vol. vii (1894) pl. xiv.

the Malvern and Abberley Hills was, indeed, so great that nowhere is any considerable thickness of Upper Coal Measures left, though these clearly extended at one time over some of the higher portions of the chain. Their removal has taken place nearly or quite down to the level of the old plain on which they were deposited, and in most cases denudation has progressed still further, so that the Haffield Breccia rests directly upon older rocks.

XX. The Relations of the Trias to the 'Permian' (Haffield Breccia) and to the Older Rocks of the Malvern and Abberley Hills.

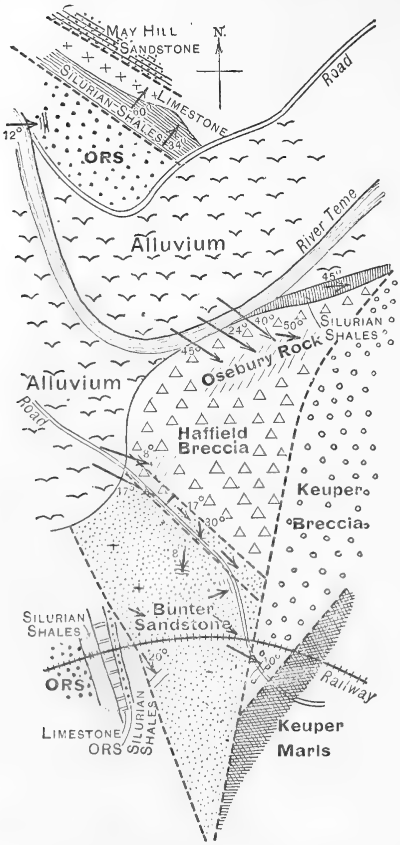
As long ago realized by Holl, the Trias is let down, together with the rocks upon which it rests, all along the eastern side of the Malvern and Abberley Hills.[1] No beds older than the Haffield Breccia appear on the eastern side of the main fault; the relations of the Trias to the Lower Palæozoic and Archæan rocks on this side of the fault are, therefore, not determinable. Triassic beds, however, occur on the western side of the fault in two localities: namely, at Knightwick, and at the extreme southern end of the Malverns, in the district about Bromesberrow. This circumstance indicates that the Trias formerly extended across the site of the fault on to the rocks of the Ranges.

In the former locality (see map, fig. 28, p. 186), the Haffield Breccia of Osebury Rock rests, dipping east-south-eastward at angles varying from 8° to 50°, unconformably (as stated by Phillips[2]) upon green Silurian shales (? Wenlock) with bands of limestone dipping east-north-eastward at 45°. On the east the Haffield Breccia is faulted against the Keuper Breccia, and on the south against a thin slice of the Haffield Breccia itself and of Bunter Sandstone. This slip is again faulted against a larger patch of Bunter Sandstone, bounded on the east by a fault bringing it against the Keuper Breccia and Keuper Marl, and on the west by a fault bringing it against the Silurian of Lord's Wood. The Keuper Breccia and Sandstone are again faulted against the Keuper Marls. The relation of the Bunter Sandstone to the Haffield Breccia is admirably exposed in the thin strip, a good section of which is shown along the road (fig. 29, p. 187). Mention was made of this section by Phillips, who recognized its importance.[3]

The massive Haffield Breccia, dipping 17° east-south-eastward, is overlain with apparent conformity by the Bunter Sandstone. A small fault has let down the rocks on the south-eastern side, and causes the apparently conformable junction to be once more revealed, giving rise to the deceptive appearance of a band of breccia in the sandstone. The junction of the two series is, however, quite sharp in both places, there being no passage between them, and I could detect no traces in the sandstone of pebbles or

[1] Quart. Journ. Geol. Soc. vol. xxi (1865) pp. 95 & 96.
[2] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 161.
[3] *Ibid.* pp. 113 & 160.

Fig. 28.—*Map of the district around Osebury Rock, near Knightwick.* (*See p. 185.*)



[Scale: 6 inches = 1 mile. The arrows represent the directions of dip.]

Heavy broken lines = Faults; ORS = Old Red Sandstone.

chips of rock such as characterize the breccia. The sandstone is soft, bright red, and much false-bedded. It is well exposed again in some quarries south of the road, and also at the railway-bridge, where it loses its bedded appearance and becomes massive. This sandstone agrees in every way with the Upper Soft Red Bunter Sandstone of the surrounding district, and of Worcestershire generally, and may, without hesitation, be correlated with this rock. On the west the Bunter Sandstone is faulted against a much folded and dislocated series of Silurian shales and limestone and Old Red Sandstone, well exposed in the railway-cutting.

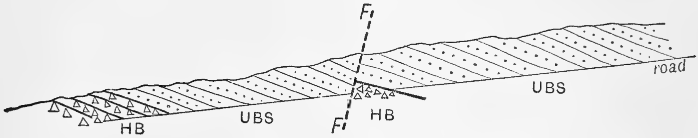
Close to the railway-station the Bunter Sandstone is faulted against basal Keuper beds consisting of alternating breccias and sandstones, greatly broken up by small faults. At one spot a band of breccia lies upon an eroded surface of sandstone. A similar section is seen at the railway-station. The Bunter Sandstone, the Keuper Sandstones and Breccias, and the Keuper Marls are all separated here by faults. The pebbles in the Keuper Breccias are very similar to those of the Haffield Breccia, but seem to be more varied in general character, for they include varieties of rock, such as quartzite, fragments of which are rarer in the older breccia.

A similar series of beds is seen at Alfrick, on the eastern side of the main fault. A mass of Haffield Breccia, noted by Phillips,[1] but

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 160.

not represented in the Survey maps, is admirably exposed in the road between Alfrick Pound and Knapp Farm. This, dipping between 46° and 65° north-eastward, strikes towards the Silurian limestones

Fig. 29.—*Section along the road south of Osebury Rock.* (*See p. 185.*)



[Length of section = about 60 yards.]

UBS=Upper Bunter Sandstone.
HB=Haffield Breccia. *FF*=Fault.

and shales, against which it is evidently faulted. It is also faulted against a red false-bedded sandstone overlain by massive red sandstone, in neither of which pebbles or chips of stone were detected: these sandstones evidently represent the Upper Bunter. The massive sandstone in its turn is thrown, by a curved fault seen in the road, against the Keuper Breccias and Sandstones; a fine exposure of these, recorded by Phillips (*loc. cit.*), may still be seen in the road south-south-east of Patche's Farm. They are followed to the north by Keuper Marls with white sandstones, such as mark the lower part of the Marls and the upper part of the Sandstone. It would seem highly probable that the succession is essentially similar to that at Osebury Rock and Knightwick Station.

In the district about Bromesberrow the succession again appears to be the same. The Haffield Breccia on the southern slopes of Howler's Heath, dipping 10° southward, is followed by the soft, bright-red Bunter Sandstone, dipping 16° south by east. The two rocks are, however, probably separated by a fault. To the south come the Keuper Breccias and Sandstones.

It would thus appear that throughout the length of the Malvern and Abberley Ranges the Upper Bunter Sandstone forms the base of the Trias, and was deposited on the Haffield Breccia. The Haffield Breccia, itself resting upon some of the higher portions of each of the Ranges, was evidently deposited originally over most, if not the whole, of the chain; and it is therefore to be inferred that the apparently conformable Upper Bunter Sandstone, with the overlying portion of the Trias, similarly buried the old chain.

It has been supposed [1] that, at least along some portions of the Abberley Range, various beds of the Trias have been deposited against a shore formed by the range, but I shall endeavour (pp. 190 *et seqq.*) to show that the available evidence is all against this view.

[1] Phillips, Mem. Geol. Surv. vol. ii (1848) pt. i, pp. 113, 132, 133 & 207: & Hull, 'Trias & Permian of Midlands' Mem. Geol. Surv. 1869.

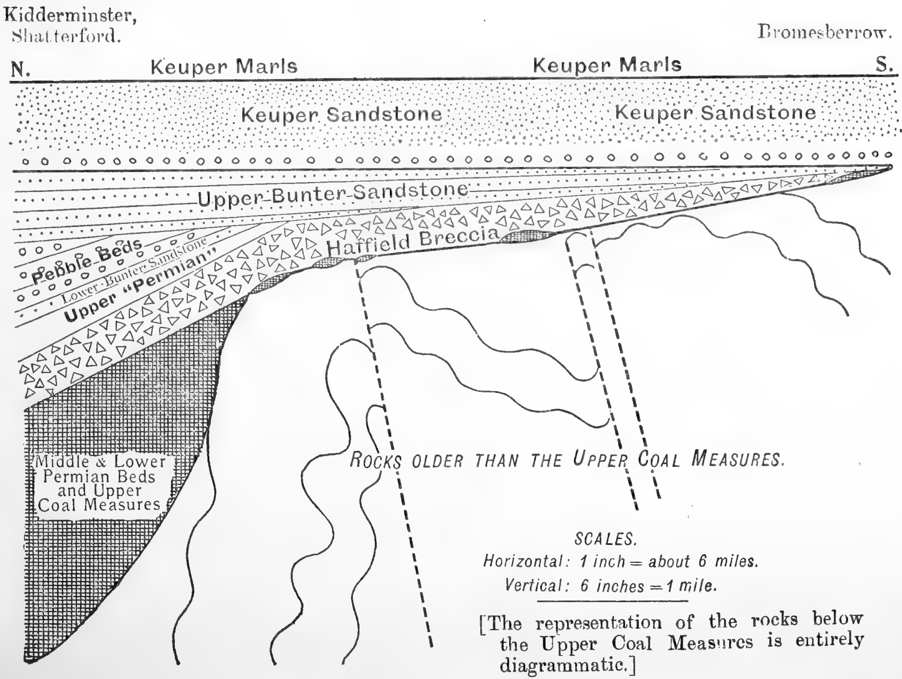


Fig. 30.—*Diagram showing the supposed relations of the Trias, Permian, and Carboniferous one to the other and to older rocks, in the tract immediately east of the Malvern and Abberley Hills, the Keuper being supposed horizontal.*

When traced south of Bromesberrow, the Keuper Breccia and Sandstone are known to overlap the Bunter and rest directly either upon the Coal Measures or upon the Old Red Sandstone, which underlies the latter. This phenomenon evidently marks merely a phase of the well-known southerly overlap of the upper members of the Trias of the Western Midlands.[1] About Kidderminster the whole of the Triassic Series is well developed; at Knightwick the Lower Soft Red Sandstone and the Pebble Beds of the Bunter have disappeared, and the Upper Soft Red Sandstone rests directly upon the Haffield Breccia. South of Bromesberrow the Upper Soft Red Sandstone disappears; and still farther south, as is well known, the Keuper Marls, or even the Rhætic beds, rest directly upon Palæozoic rocks. The accompanying diagram (fig. 30, p. 188) shows the probable relations of the various formations between Kidderminster and Bromesberrow.

If the views set forth in the foregoing pages be correct, it follows that:—

(1) The Upper Bunter Sandstone forms the base of the Trias all along the line of the Malvern and Abberley Ranges, and this is owing to the generally recognized overlap of the upper members of the Trias as they are traced southward.

(2) The Trias rests upon the Haffield Breccia without much difference in dip (no difference is perceptible in the only junction actually seen).

(3) There is no passage between the Haffield Breccia and the base of the Trias, the junction being an unconformity. The Breccia, therefore, cannot be regarded as the variable base of the Trias, unless indeed it represents horizons below the Lower Bunter Sandstone (which is the lowest member of the Trias at present recognized), for the latter rests unconformably upon all three members of the 'Permian,' including the Trappoid Breccia.[2]

XXI. The Post-Liassic Faults.

The most important of the faults which have affected the Malvern and Abberley districts since Palæozoic times is that on the eastern side of the chain. The eastern boundary of the Archæan and Palæozoic rocks, when traced from the northern end of Abberley Hill to the southern end of Chase End Hill, shows a sinuous course, like that taken by a number of the post-Triassic faults of the Midlands. The sinuosity in the present case is so marked as to

[1] Hull, Quart. Journ. Geol. Soc. vol. xvi (1860) p. 63; 'Trias & Permian of Midlands' Mem. Geol. Surv. 1869, p. 108; see also H. B. Woodward, 'Geol. of Engl. & Wales' 2nd ed. (1887) pp. 221 *et seqq.*, & Jukes-Browne, 'Building of Brit. Is.' 1st ed. (1888) pp. 118 & 122.

[2] Hull, 'Trias & Permian of Midlands' Mem. Geol. Surv. 1869, p. 32; & Cantrill, 'Geol. of Wyre Forest Coalfield' 1895, p. 35.

suggest rather an old shore-line than a fault. Phillips, however, recognized the faulted character of the junction with the Trias, but evidently considered that the fault had been formed before the epoch of the New Red Sandstone (under which term he included not only the Trias, but also the Haffield Breccia), and that the beds of this formation had been deposited against an old shore bounded by the fault.[1] Phillips was presumably led to take this view from the circumstance that the old rocks of the range had been undoubtedly disturbed and elevated before the deposition of the New Red Sandstone, and now stand up much in the manner of a coast-line with several bays; in these sheltered recesses, he supposed that breccias, in part derived from the hills themselves, were deposited.

Prof. Hull later to some extent shared this view, and regarded the Malvern and Abberley Hills as part of a shelving shore against which the Triassic beds overlapped[2]; the northernmost portion of the Abberley Range, indeed, he supposed to be an actual relic of the old cliff against which the Trias was deposited. He concluded, however, that, judging from the relative positions of the Permian Breccia and the Trias, the former had undergone extensive disturbance before the Triassic period (*op. cit.* p. 16).

In the Geological Survey map of the district (Sheet 43, N.E.), the fault which runs along the eastern face of the Malverns is represented as dislocating the Triassic beds farther south, though in Phillips's map (*op. cit.* pl. i) there is no indication of this. I have been unable to determine who was responsible for the introduction of the southerly extension, or when it took place; but clearly it represents a modification of Phillips's view. Holl, also, regarded the fault as of post-Liassic age.[3]

I have carefully followed the whole of the eastern margin of the old rocks of the Malvern Range, as also much of that of the Abberley Range, and conclude (1) that there is no clear evidence that these hills ever formed the margin of the Triassic waters; (2) that the Triassic rocks have been brought into juxtaposition with the older rocks of the chain by a post-Liassic fault.

The actual junction of the rocks on the two sides of the boundary has rarely been seen, but its position is generally determinable by a somewhat sudden change in the angle of slope, the gentle surface of the softer Triassic beds abruptly giving place to the steeper incline of the Archæan or Silurian surface.

The outcrop of the several horizons of the Haffield Breccia and the Trias shows a marked independence of the course of the boundary-line, as may be seen by an examination of the Geological Survey map of the district. Indeed, a number of undulations transverse to the direction of the Ranges end sharply against the older rocks composing the latter, and various members of the Trias and

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, pp. 6, 49, 140, 164, & 207.
[2] 'Trias & Permian of Midlands' Mem. Geol. Surv. 1869, pp. 16, 62, & 67.
[3] Quart. Journ. Geol. Soc. vol. xxi (1865) p. 101.

the Haffield Breccia strike up against the junction. Moreover, according to my experience, nowhere do the Triassic beds, as they are traced towards the hills, assume a marginal character comparable with that of the Keuper Marls in the Tortworth and Bristol districts (Dolomitic Conglomerate). The more frequent occurrence of sandstones and breccias close to the hills is due to the rise of the older and coarser beds (Haffield Breccia and Bunter Sandstone) towards the west, owing to post-Liassic elevation of the Ranges. The combined effect of this movement and of those along the transverse lines, to which reference has just been made, has resulted in bringing up to the surface the coarser beds in certain localities, supposed by Phillips to indicate former bays along the old coast-line.[1] Thus, the more frequent occurrence of sandstones and breccias close to the hills is no proof of the proximity of a shore-line in that direction.

With regard to the nature of the materials in the Haffield Breccia and the Trias, after making extensive collections from various localities in the neighbourhood of the Malvern and Abberley Hills, I have come to the conclusion that these materials are not such an assemblage as could have been derived from the denudation of those hills. It is true that a relatively small proportion of the fragments agree closely with rocks seen there, but they may well have been derived from other similarly-constituted lands, such as those of the neighbouring 'Mercian Highlands' of Mr. Wickham King, which in early Triassic and in pre-Triassic times may have been almost, or quite, continuous with the eastern side of the Malverns. It is to be hoped that further light will be thrown on the lithological aspect of the problem in Mr. King's forthcoming memoir on the fragments of the Haffield Breccia and Trias of the Western Midlands, in view of which the question is not discussed here.

A careful search along the eastern side of the whole of the Malverns, and in that portion of the Abberley Range near Cowleigh Park, Storridge, Alfrick, Knightwick, Ankerdine, Martley, and the whole of the range north of this point, failed to reveal any evidence of direct superposition of the Trias upon the Lower Palæozoic or Archæan rocks of the chain. The whole of the evidence seen appeared to be compatible with the view that the junction is a fault. If the evidence given in pp. 183–91 of this paper be accepted, the depressed position of the New Red Sandstone (and Permian) on the eastern side of the ranges can be explained only by the assumption of post-Liassic faulting.

The fault-breccia is known to occur at three spots along the Malvern Range. It was evidently seen in the Malvern Tunnel by Symonds & Lambert.[2] It is still visible on the eastern side of Midsummer Hill,[3] and is well exposed in the large quarry at Malvern Link. In each of the two last-named localities it consists

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, pp. 113, 132.
[2] Quart. Journ. Geol. Soc. vol. xvii (1861) pp. 153, 155.
[3] *Ibid.* vol. lv (1899) p. 138.

of angular fragments of Archæan and Triassic rocks. The fault itself was apparently seen by Phillips on the eastern side of some portion of the Malvern Range, where it dipped 60° eastward.[1] At Malvern Link the faulted surface of the Archæan massif, with its covering of breccia, is admirably shown. The fault here displays its characteristic sinuous course, and dips north-eastward at 65° to 75°, usually between 65° and 70°. It is, therefore, a normal fault.

The throw of the fault was reckoned by Strickland at about 2½ miles.[2] But in this estimate no account was taken of the unconformity at the base of the Haffield Breccia, although this had been previously described by Phillips (*op. cit.* p. 112). Accordingly a great thickness of Carboniferous, Old Red Sandstone, and Silurian has to be deducted. The throw may be estimated by comparing the position of the Trias and Permian at adjacent points on the two sides of the fault, the thickness of the Haffield Breccia and of the various members of the Trias being estimated with the aid of fig. 30 (p. 188), which is based on the known thickness of the rocks concerned. In my opinion this method will give fair approximations to the truth. Calculations made in this way indicate that the throw varies from less than 200 feet at the southern end of the Malverns to about 1000 feet at Woodbury Hill.

A remarkable feature of this fault is the curious way in which it tends to follow a line parallel to the western margin of the old mountain-chain; it repeats in a striking manner the sinuosities of the latter. This appears to indicate either a connexion between the post-Liassic faulting and earlier movements, or a mechanical relation between the former and the disposition of the component rocks of the range.

In addition to the main fault, other post-Liassic faults have affected the area: among these are the transverse faults near Knightwick Station. A transverse dislocation of the main fault has followed the old fault-line running down the Gullet Pass.[3] Such dislocations of the eastern fault may be only apparent, the latter having perhaps had from the first a zigzag course. Many small faults traverse the Trias and various parts of the Malvern and Abberley district, and possibly some of the faults which affect the Cambrian and Silurian west of the hills may be of post-Liassic age.

From the foregoing considerations I conclude that:—

(1) The 'Permian' (Haffield Breccia) and Trias were **not** deposited against a shore-line formed by the Malvern and Abberley Ranges, which do not appear to have had, during the period of this deposition, an existence independent of the tract to the east.

(2) The Haffield Breccia and Upper Bunter Sandstone together passed over much, if not the whole, of the two Ranges.

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 140.
[2] Phil. Mag. ser. 4, vol. ii (1851) p. 363.
[3] Quart. Journ. Geol. Soc. vol. lv (1899) p. 148.

(3) The present relation of the Permian and Trias to the Malvern and Abberley Ranges is due to a post-Liassic fault of moderate downthrow.

XXII. Movements other than the Hercynian in the Malvern and Abberley Districts.

Early movements which appear to be independent of the Hercynian folding have left their traces in the Western Midlands. In addition to these, a well-marked series of later movements took place, which followed the lines of the old Hercynian folds. Similar instances in many tracts of country have long been known, and our knowledge of such posthumous movements has been utilized by Godwin-Austen and other geologists to settle questions of great practical importance. It is proposed to defer the discussion of such movements in the Malvern and Abberley districts to a future occasion.

XXIII. Summary of the Structure of the Malvern and Abberley Ranges.

1. The tract of country which includes the Abberley Hills, the Malvern Hills, May Hill, the Old Red Sandstone district west of these, the Forest-of-Dean Coalfield, the Coalfields of South Wales and Bristol, and the district of Tortworth, is traversed by a series of related folds. The axes of these run in two chief directions, intersecting one another at a considerable angle. The axial plane of one set tends to dip in an easterly, and that of the other in a southerly direction. (See p. 179.)
2. In the Malvern and Abberley district much overfolding has taken place, frequently from the east, more rarely from the south. The inversions are not confined, as Phillips supposed,[1] to the Abberley Hills and the northern and middle portions of the Malvern Range, but also affect beds in the southern part.[2] Inversion is, in fact, the rule along the western side of the Malverns. The amount of inversion is frequently considerable, and in some places in the Abberley district the beds are completely overturned. The evidence obtainable militates against the idea of overlap of the Lower Palæozoic beds suggested by Holl. (See pp. 143, 150, 163.)
3. The western margin of the Archæan massif appears everywhere to be defined by a fault, in some cases about vertical, in others reversed, sometimes with a considerable hade. The result of these thrusts is that the Archæan has been shoved on to various zones of the Cambrian at the southern end of the Malvern Range,[3] and in other parts of the chain on to various zones of

[1] Mem. Geol. Surv. vol. ii (1848) pt. i, p. 71.
[2] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 154 & 155.
[3] *Ibid.* p. 155 & map, pl. xiii.

the Silurian, so that in some places the May Hill Sandstone (pp. 139, 142, 149, 152, & 160), in others the Woolhope Limestone (Pl. VIII), and in others the Wenlock Shale (p. 142) are in contact with the Archæan. At West Malvern the Cambrian appears to have been thrust on to the May Hill Sandstone (p. 158); in Cowleigh Park, the Archæan on to the same formation (p. 157); and near Martley the Archæan appears to have been thrust horizontally over the basal Cambrian, and these two again on to the Old Red Sandstone (p. 163). In other parts of the Abberley Range portions of the Silurian Series appear to have been thrust over other portions of the same series (pp. 167–73). Thrusts of the Archæan massif on to the Cambrian and Silurian rocks have taken place also within the present limits of the massif itself.[1]

4. The overthrusts and upthrusts appear to have been to a certain extent independent of the first folding of the rocks, but are closely connected with the process of overfolding which took place later. (See p. 182.)
5. The thrusts in most cases do not appear to have materially modified the nature of the rocks concerned in the process, but in some places a secondary production of schists (mylonites) has probably taken place in the Archæan material in the neighbourhood of the thrust-planes. (See p. 183.)
6. In some cases a secondary folding appears to have affected the thrust-planes, in a way similar to that seen in the Scottish Highlands. (See p. 163.)
7. The intensity of folding diminished west of the old ranges, and in places a typical austönungszone is seen.[2]
8. The movements undergone by the chain were complicated by the production of transverse faults, the blätter of German writers.
9. The West-of-England Chain appears to have been developed in several sections, the chief movements of the rocks having progressed from north to south. (See p. 182.)
10. The western fronts of these sections show some tendency towards convexity in the direction of movement, as in the case of other more important ranges. (See p. 183.)
11. The rocks affected by the great movements range from the Archæan to the older Coal Measures. (See pp. 165 *et seqq.*) The Archæan mass itself in the Malverns shows deep and narrow crushed infolds.[3]
12. The Upper Coal Measures and the 'Permian' rest relatively undisturbed upon the denuded rocks of the old chain. This favours the view that the West-of-England Chain is a

[1] Pp. 146, 149, 150, 152, & Quart. Journ. Geol. Soc. vol. lv (1899) pp. 142 *et seqq.*, pp. 150 *et seqq.*

[2] Quart. Journ. Geol. Soc. vol. lv (1899) p. 156.

[3] *Ibid.* pp. 142 *et seqq.*, pp. 150 *et seqq.*; see also pp. 146–47 & 152 of the present paper.

member of the great Hercynian mountain-system, itself produced chiefly during Coal-Measure times. (See p. 183.)

13. The movements parallel to each of the two sets of axes marking the folds both of the Western Midland district and of the coalfields of Southern Britain took place chiefly in the limited interval between the deposition of the older and the newer Coal Measures. The two movements were, therefore, practically simultaneous, as in the case of the two sets of intersecting folds on the Continent. (See pp. 180–182.)
14. The Haffield Breccia is unconformable, not only to all the older rocks of the Malvern and Abberley Ranges, but also to the Upper Coal Measures. It was deposited over much, if not the whole, of the two ranges. (See pp. 165, 183.)
15. There is no evidence to prove that the Malvern and Abberley Hills formed part of a shore-line against which the Triassic beds were deposited, for the Upper Bunter Sandstone appears to form the base of the Trias throughout the Malvern and Abberley district, and rests unconformably, but without appreciable difference of dip, upon the Haffield Breccia, together with which it passed over the site of the West-of-England Chain. (See pp. 185, 189.)
16. The 'Permian' (Haffield Breccia) and Trias are let down on the eastern side of the hills by a post-Liassic fault, the downthrow of which has been greatly overestimated. This brings various portions of the Trias against the Lower Palæozoic and Archæan of the old chain. The fault follows to a remarkable extent a line parallel to the western front of the old ranges. (See pp. 190, 192.)

    With this movement the present Malvern and Abberley Ranges, constituting the original western front of the old mountain-land, became for the first time defined, and separated from the rest of the latter: this, having been sunk with the overlying Permian and Trias, remains still buried, while denudation has laid bare the older rocks of the West-of-England Chain itself.[1]
17. In addition to the post-Liassic faulting, other movements have affected the Malvern and Abberley area since Coal-Measure times. These movements have often followed the lines of the Hercynian folding. (See p. 193.)

EXPLANATION OF PLATE VIII.

Geological Map of the Middle and Northern Portions of the Malvern Range and of the Southern Portion of the Abberley Range on the scale of 3 inches to the mile.

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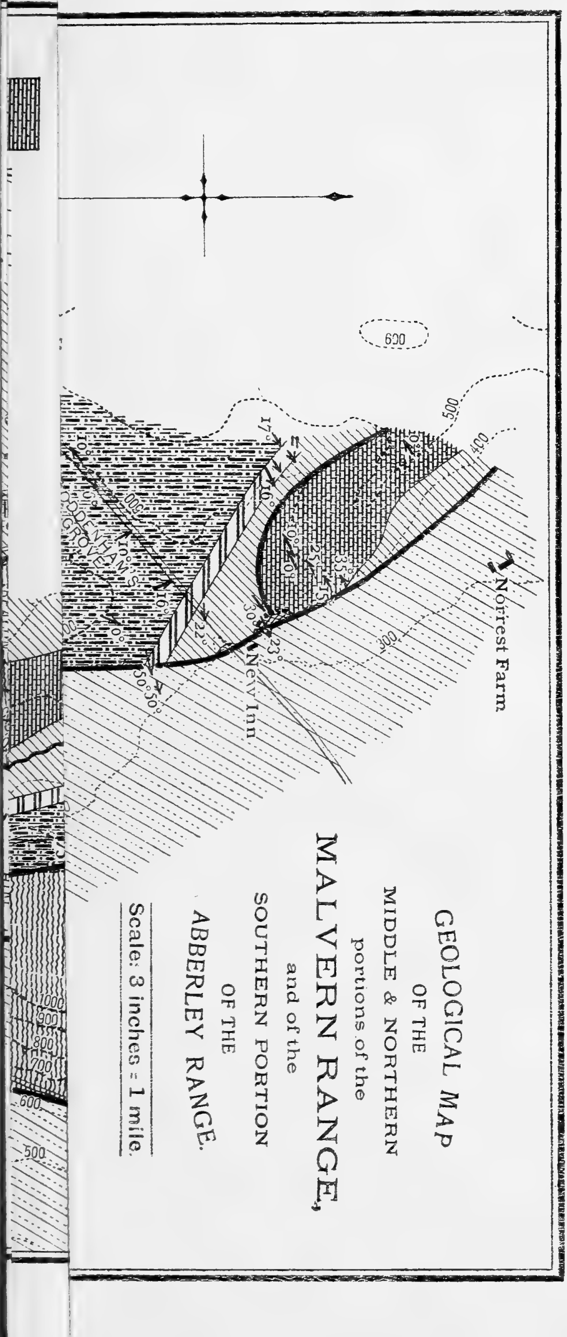
[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 156 & 157.

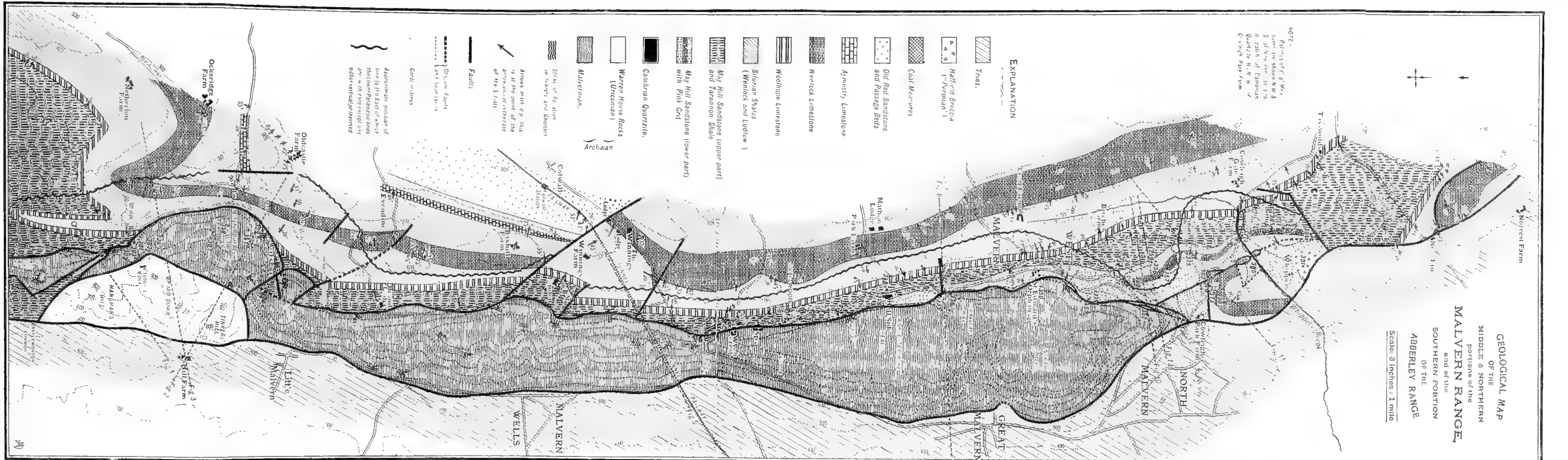
Discussion.

Sir Archibald Geikie, in response to a call from the President, remarked that, having no personal acquaintance with the ground described in the paper, he hardly felt himself competent to offer any criticism. He had listened, as they all had done, with great admiration of the skill with which the complicated structure of a hill-range had been dissected in the field and expounded by the Author. To a geologist familiar more particularly with the types of dislocation presented by the older rocks, it could not but be of extreme interest to find these types repeated, even in minute detail, among rocks so late as the Coal Measures. The account given in the paper of the faults of the region, taken in connexion with the subject of the previous paper by Dr. Davison,[1] recalled to the speaker's memory an opinion expressed to him many years ago by the late Mr. Richard Gibbs, who, as Fossil-collector to the Geological Survey, proved himself to be a shrewd observer, and as a native of Gloucestershire had been familiar with the Malvern Hills from boyhood. He believed that there is reason to think that the great post-Triassic fault along the eastern side of that chain of hills is still moving. Sir Archibald had never been able to obtain any confirmation of this opinion, but it was held so positively by so good a geologist that he had often wished to know whether any precise watch had been kept along the line of the fault, with the view of detecting a possible movement. He would like to ask the Author whether he had looked into the question, and particularly whether any examination of the ground had been made after the last earthquake that affected it.

Mr. Wickham King supported the Author's conclusions that there were great earth-movements in the Carboniferous period resulting in the overthrust of Archæan and other rocks to the west, and said that his own work in the Silurian ground agreed with much of that so graphically described by the Author. He was, however, unable to agree with some of the conclusions relating to the so-called 'Permian' (Haffield) breccias and the Trias. The sandy nature of these Haffield breccias agreed more with the sandy Bunter and Keuper breccias existing on the northern flanks of the Abberley Hills, than with the marly breccias interstratified with the Enville Permians. There is no known stratigraphical evidence below these Haffield breccias to prove their age; they contain no fossils; and though at places there is some appearance of an upward transition of these breccias into Triassic Sandstones, yet the earth-movements have affected the breccias and sandstones so much that decisive proof is difficult to obtain. We should therefore adopt the name given to them by Prof. Phillips of 'Haffield Breccias,' until further proofs are announced. He agreed with the views repeatedly expressed by Prof. Lapworth, that in the Carbo-Triassic periods highlands existed south of the Lickey and east of the Malverns, that much of the talus derived

[1] 'On the Cornish Earthquakes of March 29th to April 2nd, 1898,' pp. 1–7 of this volume.


GEOLOGICAL MAP
OF THE
MIDDLE & NORTHERN
portions of the
MALVERN RANGE,
and of the
SOUTHERN PORTION
OF THE
ABBERLEY RANGE.
Scale: 3 inches = 1 mile.
Norrest Farm
New Inn
600
500
400
300


GEOLOGICAL MAP
OF THE
MIDDLE & NORTHERN
portions of the
MALVERN RANGE,
and of the
SOUTHERN PORTION
OF THE
ABBERLEY RANGE
Scale: 3 inches : 1 mile
EXPLANATION
Trias.
Haffield Breccia ("Permian")
Coal Measures
Old Red Sandstone and Passage Beds
Aymestry Limestone
Wenlock Limestone
Woolhope Limestone
Silurian Shales (Wenlock and Ludlow)
May Hill Sandstone (upper part) and Tarannon Shale
May Hill Sandstone (lower part) with Pink Grit
Cambrian Quartzite.
Warren House Rocks (Uriconian)
Malvernian.
Archæan
Faults
Ockeridge Farm
Oldcastle Farm
MALVERN WELLS
GREAT MALVERN
NORTH MALVERN
Little Malvern

from them was from time to time redistributed, and that the remaining stumps of the highlands were buried beneath the Keuper Marls.

Prof. WATTS remarked that the Author had worked out the structure of the Malverns by detailed study of the simpler and fossiliferous Cambrian and Silurian rocks on the flanks of the range. He hoped that the Author would extend his study to the more difficult crystalline rocks of the central range. He enquired whether it was certain that the Martley quartzite was of the same age as that of the Lickey Hills.

The AUTHOR thanked the Society for the cordial reception given to his paper. In reply to Sir Archibald Geikie, he stated that he had been unable to detect any evidence of recent movement along the great fault on the eastern side of the Malvern Range. To Prof. Watts he replied that the Martley quartzite, while resembling macroscopically and microscopically the Cambrian quartzites of Hartshill and the Malverns, differed greatly from any other rock in the district, including the metamorphic quartzites of the Malverns.

9. *On a* Particular Form *of* Surface, apparently *the* Result *of* Glacial Erosion, *seen on* Loch Lochy *and* Elsewhere.

By W. T. Blanford, LL.D., F.R.S., Treas. G.S. (Read January 10th, 1900.)

[Plate IX.]

There is a form of surface, the result, I believe, of glacial action and subsequent subaerial denudation, of which I have now seen examples in widely-separated areas. I first noticed it on Lake Como, then in the Great Glen of Scotland, and again in British Columbia.[1] These are the only striking instances that I have seen, but smaller and less conspicuous examples appear to be common in valleys that have been traversed by glaciers.

The surface in question consists of an almost even plane, sloping at a moderate or high angle, and cut at intervals by small ravines or channels, along which rain drains off.

I think it probable, indeed almost certain, that this peculiarity must have been noticed by other geologists. I have not succeeded in finding any description of it, despite some search, but I shall not be surprised if it has attracted the attention of some among the many eminent observers who have studied the glacial phenomena of Scotland, and if it has been fully described, perhaps by more than one. I do not call attention to the peculiar surface because I think it new to geologists, but because I believe, for reasons that will appear in the sequel, that this combination of glacial and freshwater erosion is worthy of further examination and record. I should perhaps have published some notes on it before, had I been able to obtain photographs or figures of the locality, but until recently I have been unable to procure any. Last August, I made use of a fortnight's leisure to revisit Loch Lochy, and my son made some photographs of the scenery. The accompanying Plate (IX) reproduced from two of these photographs may, I hope, serve to explain the peculiarities to which I am calling attention.

The Great Glen of Scotland, traversed by the Caledonian Canal, is one of the best known tourists' routes in the British Islands. It has been repeatedly described,[2] and it well deserves the attention of all geologists and physical geographers, for it is a remarkable valley in many ways, in no respect more than in its extraordinary straightness of direction, which is approximately north-east and south-west. As is well known, the bottom of the Glen is chiefly

[1] The locality on Lake Como is east of the lake, a short distance north of the town of Como itself. That in British Columbia is on a hill opposite Lord Aberdeen's ranch at Vernon. The Scottish example is here described.

[2] There is an excellent account of it in Sir Archibald Geikie's 'Scenery of Scotland' 1st ed. (1865) p. 177, & 2nd ed. (1887) p. 234.

taken up by three lakes—Loch Ness, which is by far the longest, to the north-east, Loch Oich in the middle, and Loch Lochy to the south-west: the water-parting of the Glen being between Loch Oich, which runs out north-eastward into Loch Ness, and Loch Lochy, which drains south-westward into the arm of the sea known as Loch Eil. The sides of the Great Glen show abundant evidence of glacial action throughout, and it is of course an elementary fact in the history of the Glacial Epoch that this Glen was occupied by a large glacier during the whole time that the Highlands of Scotland were wholly or partly covered with ice.

The sides of the Glen have, I think, been *planed*—if the expression is permissible—by glacier-action to a greater extent than is usual in glaciated slopes. This is especially the case on the south-east side of the Glen, near the head (or north-eastern end) of Loch Lochy,[1] and in the interval of $1\frac{1}{2}$ miles between Loch Lochy and Loch Oich, near Laggan. Here the sides of the Glen, up to a height of about 1000 feet above the sea (Loch Lochy itself is only 93 feet above tide-level), form a singularly regular and flat slope of about 35°, as shown in Plate IX. The numerous channels cut by the streams that drain the slope are, on an average, not more than 10 or 15 feet deep. Occasionally a deeper channel is seen; some may be perhaps 50 feet deep, but this is quite exceptional. The channels, where they are deepest and most numerous, near Laggan, occupy less than a fourth of the surface.

At intervals deep glens intersect the crests of the hills, which rise to a height of about 2000 feet above the sea. These glens, in the higher hills, are frequently 500 feet deep or even more,[2] but the streams from the glens run out in comparatively shallow ravines cut in the sloping plane that forms the side of the Great Glen.

The rocks exposed in Loch Lochy and Loch Oich are chiefly crystalline schists and gneissose rocks. But the surface of the hill-range to the south-east of Loch Oich and of upper Loch Lochy is shown on Geikie's Geological Map of Scotland to be formed by a narrow band of Devonian strata, cut off to the north-west by the fault which runs throughout the Great Glen. It is probable that the peculiarly even slope of the hillside in this part of the Glen is connected with the lithological character of the Devonian. The hill south and south-east of Laggan, represented in the left half of Plate IX, is composed of a hard sandstone that appears to disintegrate on exposure much more rapidly than the schistose and gneissose formations of the neighbourhood. To this disintegration, probably, may be attributed the great amount of freshwater erosion exhibited, the hill south of Laggan being traversed by far more watercourses than the remainder of the smoothed area, or than the

[1] Glen Roy, with its famous Parallel Roads, is within 4 or 5 miles to the south-east, being just beyond the range of hills that here forms the south-eastern side of the Great Glen.

[2] These measurements are taken from the Ordnance Survey map.

sides of the Great Glen in general, and those watercourses being deeper and more sharply cut. It is, of course, quite possible that the tendency to disintegration in this sandstone has facilitated glacial as well as stream-erosion.

Here and there, in going along the surface and examining the small sections recently exposed by the cuttings for the new railway from Spean Bridge to Fort Augustus, patches of boulders and gravel, evidently of the nature of moraine, are found filling hollows in the slope. But these patches are of small extent; in each case that I observed them rock appeared in place in the neighbouring stream-beds, and it is not improbable that the hollows thus filled were the result of irregular erosion by either ice or running water, during Glacial times.

The explanation of the surface-features described is, I think, the following:—The sloping plane must have been produced, like other parts of the side of the Great Glen, by the planing action of a glacier. The patches of moraine, while filling up small hollows and rendering the slope more uniform, afford additional evidence of its Glacial origin. The small channels cut in the slope are clearly due to freshwater erosion since the glacier disappeared. The deeper lateral glens in the higher hills must be of pre-Glacial origin, and the rounding of their upper edges shows the action of ice upon them.

The general effect produced by the whole evidence is that which has impressed so many previous observers: the small amount of denudation that has taken place since the Great Ice Age, and the necessary deduction that not many thousands of years can have elapsed between the Glacial Epoch and the present day.

There were two points, illustrated by the surfaces of which I have endeavoured to indicate the principal features, that are worthy of notice, and they will, I hope, serve to excuse my calling attention to what may be, to many, a familiar variety of the surfaces affected by glacial action. I may premise by saying that in glaciated surfaces it is generally very difficult to determine precisely how much of the erosion is post-Glacial, whereas in the peculiar case presented by the slopes here described it is easy to recognize which portions owe their moulding to Glacial, and which to post-Glacial action. It may be urged with apparent justice that some post-Glacial erosion must have affected the whole slope; but on the other hand it should be remembered that this erosion is excessively small, else the moraine-patches would have been worn more deeply. Moreover, in comparing the amount of denudation in the ravines and on the intervening slopes, we may neglect that on the latter because it has been uniform throughout the whole surface, and it is the excessive denudation of the stream-beds which alone has to be considered.

(i) In the first place I think that this case constitutes a particularly good example of the erosion produced by a glacier. It has become a

common practice among some geologists of late years to attach very small importance to the erosive power of glaciers.[1] This has been partly due to the fact that some lake-basins, formerly attributed to glacial erosion alone, have been shown to have owed their formation, in part at least, to other causes, and that doubts have always existed whether large deep lakes such as Loch Ness could have been excavated by glacial action. It is therefore well to point out that the origin of lake-basins is not the same question as the erosion of the sides or even the bottom of a valley by glacial action. I have not the slightest wish to enter into the question of the origin of lake-basins—a subject on which the last word has not yet been said—but I think it is evident that the slopes near Laggan have been cut away, and to a very great extent by glacial action, because no such sloping surface as is there exposed can have been produced by ordinary freshwater erosion.

There can, I think, be no reasonable question that, as has been shown by Sir Archibald Geikie,[2] the Great Glen of Scotland, at the commencement of the Glacial Epoch, was an ordinary river-valley. In this case the lateral glens, of which the higher portions remain almost as they were in pre-Glacial times, must have continued down to the valley, with ridges between them. The lower portions of these ridges, up to a height of about 1000 feet, have been completely swept away. It is impossible with any degree of precision to estimate the magnitude of these ridges; but, taking into consideration the facts that some of the higher glens, despite the Glacial denudation which has manifestly worn down the crests that separate them, are still upwards of 500 feet deep, and that the flat bottom of the main valley at Laggan is 3 furlongs or 2000 feet broad, it is probable that a thickness of at least 250 or 300 feet of rock has been removed throughout a considerable portion of the valley. The fact that the stream-beds from the higher glens are cut off by the slope and have formed shallow ravines in it is evidence that the Glacial erosion cut into the hillsides to a greater depth than the streams formerly did, and that not only the intervening spurs were abraded, but even the hillside from which they projected was planed away.

(ii) The second point is of at least equal interest. Most geologists will heartily concur with Sir Archibald Geikie's remarks in his recent address to Section C of the British Association at Dover on the importance of obtaining trustworthy estimates of geological time. Now the latest subdivision of geological time, that which has elapsed since the Glacial Epoch, is precisely that with which we ought to be best acquainted. But it is notorious that the different attempts which have been hitherto made to estimate the number of years that have passed since glaciers disappeared from the valleys

[1] Quite recently (in Geol. Mag. 1899, p. 486) Mr. A. Harker has made precisely similar remarks on the efficacy of glacial erosion, when describing its effects in the island of Skye, which is only about 40 miles west of Loch Lochy.

[2] 'Scenery of Scotland' 1st ed. (1865) p. 180.

of the Scottish Highlands vary enormously, from the 8000 or 10,000 postulated by Sir Joseph Prestwich [1] to the 80,000 years calculated on certain astronomical data by James Croll,[2] and the 200,000 or more estimated by other geologists.

If I am right in regarding the small ravines on the slopes near Laggan as entirely of post-Glacial origin, there ought, I think, to be no insuperable difficulty in ascertaining, after a certain number of years, the unknown quantity in the equation which represents the time that has elapsed since the disappearance of the glaciers. It is practicable to measure the amount that has been removed in any of the channels that furrow the surface of the slope, and all that is necessary is to determine the unknown quantity, which is evidently the average annual denudation in each stream-course. It would be necessary for the purpose of observation to obtain a careful plan of part of the hillside accurately contoured, so as to show both the breadth and depth of the channels on a given area. The best place would perhaps be the hillside along Ceann Loch (the uppermost part of Loch Lochy), beginning on the north-east at the stream called on the map Allt nan Sithean. This is the area in which stream-denudation is greatest and evidently more rapid than elsewhere. It would be advisable also to have photographs made of each stream-course so far as may be practicable. A comparison of the plan and photographs with the actual surface of the hillside a quarter of a century hence, or perhaps even sooner, would give some idea of the rate of denudation, though probably a much longer period would be needful for a correct determination of the time that has been required to excavate the channels. Possibly a rough estimate could be obtained by determining the rate at which the area occupied by ravines, now probably not exceeding one fourth of the whole area, increases at the cost of the intervals between the ravines, and this could be determined by the photographs alone. But it is probable that the rate of denudation is too slow for this plan to give useful results.

In calculating the time, it will be necessary to assume that denudation has proceeded with regularity since the disappearance of the glaciers; but this of course is not certain, because rainfall may have varied, and so may the amount of snow which accumulated in the winter, and aided denudation by flooding the streams when melting. Of course, too, the changes from severe frost to mild weather, a most potent agent in disintegration, may have been more numerous. But I cannot think it probable that, in a country where frost and snow still play an active part in the disintegration and denudation of rocks, any changes of climate that may have taken place since the close of the Glacial Epoch can have sufficiently retarded or accelerated the action of ordinary subaerial erosion to affect seriously the calculation of the time that has elapsed.

There is one concluding word that must be added. It may, as

[1] Quart. Journ. Geol. Soc. vol. xliii (1887) p. 407.
[2] 'Climate & Time,' 1875, p. 341.

View from Laggan Lock, on the Caledonian Canal, of the south-eastern side of the valley in which the upper part of Loch Lochy lies.

already stated, be many years before the denudation is sufficient to be measured with such accuracy as to give definite results. If a ravine of 50 feet deep has taken 10,000 years to cut, it has only increased its depth at the rate of 6 inches in a century. Hence it is evident that a very careful and accurate survey of some of the ravines is essential, in order that small changes of contour may be measured.

EXPLANATION OF PLATE IX.

View from Laggan Lock, on the Caledonian Canal, of the south-eastern side of the valley in which the upper part of Loch Lochy lies. [Reproduced from photographs.]

Discussion.

Mr. Harker welcomed this paper as enforcing the importance of ice-erosion in the Scottish Highlands. He had observed in Skye evidence of the widening and deepening of a main valley by ice-action, subsequently to the establishment of tributary valleys. He thought, however, that to calculate the date of the Glacial Epoch from the total post-Glacial erosion effected by a stream and its present rate of erosion would not necessarily lead to a very trustworthy result, since the present rate cannot be confidently assumed to represent the average rate throughout post-Glacial time.

Mr. Barrow said that in mapping the Highlands he had met many of these straight-sided valleys, and had noted that they coincided with the direction of movement of the ice-sheet. Whenever the valley made a sharp bend and no longer coincided with this direction, the straight-sided character was lost. This was usually as true of the minor as of the major valleys. In addition, the faces of hills on fairly open ground presented a singularly uniform slope, looking towards the direction from which the ice came. Their reverse sides differed greatly in configuration, their form depending mainly on the nature of the rocks of which they were composed.

The Rev. Edwin Hill fully agreed with the Author that the period elapsed since the Ice Age might not be long. The numerous parallel channels were a natural consequence of the uniform slope, as rain-drops run parallel down a sheet of glass. That this uniform slope was a consequence of glacial action seemed to need more evidence. Side-valleys opening at a high level on the sides of a main valley did not seem conclusive proof of the lower part being formed by ice. Such may be seen in mud-flats bordering the channel of a tidal river; nor is the difference of level in the channel above and below Niagara due to ice.

Prof. Seeley said that he had seen evidences of the small amount of denudation since the west coast of Scotland was glaciated, in the persistence of glacial grooving in exposed situations about Gairloch. But nothing was more impressive than the condition of the Parallel Roads of Glen Roy, which, though cut into by gullies similar to those

shown by the Author, were not in the parent rock, but in material which could be compared only to the Contorted Drift of the Norfolk coast. Yet the 'roads' were rarely cut into for half their width by subaerial denudation; whereas in the East of England the Boulder Clay was often completely removed or only capped hills, while valleys were excavated in the underlying deposits, which appeared to show that denudation had done comparatively little to alter the West of Scotland since the Great Glaciation.

The AUTHOR, in reply, expressed his satisfaction at the remarks made by Mr. Harker and Mr. Barrow. Replying to Mr. Hill, he regretted that he had not sufficiently insisted upon the fact that a sloping plane, like that seen on Loch Lochy, could not be due to freshwater erosion; it must be, he thought, of glacial origin, and the higher glens were clearly truncated by this sloping plane. The point noticed by Prof. Seeley, that the Parallel Roads of Glen Roy showed less post-Glacial stream-erosion than the hillside on Loch Lochy, was due to the latter being composed of a Devonian rock which appeared to undergo comparatively rapid disintegration near the surface.

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Vol. LVI. MAY 30th, 1900. **No. 222.**
PART 2.

Chas. A. White

THE

QUARTERLY JOURNAL

OF THE

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10. CONTRIBUTIONS *to the* GEOLOGY *of* BRITISH EAST AFRICA.—PART II.[1] *The* GEOLOGY *of* MOUNT KENYA. By Prof. J. W. GREGORY, D.Sc., F.G.S. (Read January 24th, 1900.)

[PLATES X, XI, & XII (*pars*).]

CONTENTS.

I. INTRODUCTION.

MOUNT KENYA, the greatest mountain in British East Africa, was discovered by Ludwig Krapf,[2] when on December 3rd, 1849, he saw its two-horned summit from a hill above the Wakamba village of Kitui. No suggestion as to the structure of Kenya was made until 1883, when Joseph Thomson, after a view of the mountain across the Laikipia plateau, described it as the denuded remnant of an old volcano. 'The peak,' he tells us,[3] 'without a doubt represents the column of lava which closed the volcanic life of the mountain . . . . The crater has been gradually washed away.' The first definite geological information about Kenya we owe to Count S. Teleki, who was the first European to reach the mountain; in 1887 he climbed the western slopes to the height of about 13,800 feet, and brought back some rock-specimens which have been described in detail in a valuable memoir by A. Rosiwal.[4] This petrologist determined the specimens as augite-andesite, andesite-pitchstone (hyalo-andesite), and phonolite, and thus proved the volcanic nature of the mountain.

[1] Part I, 'The Glacial Geology of Mount Kenya,' was published in this Journal, vol. l (1894) pp. 515–530, with maps, etc.

[2] 'Travels, Researches, & Missionary Labours . . . in Eastern Africa' 1860, p. 544.

[3] 'Through Masai-Land' 4th ed. (1887) p. 224.

[4] 'Ueber Gesteine aus dem Gebiete zwischen Usambara u. dem Stefanie-See' Denkschr. d. k. Akad. d. Wissensch. Wien, vol. lviii (1891) pp. 496–498.

Teleki's account of the structure of Mount Kenya differed, however, from that of Thomson. The former climbed through the forest-belt from Ndoro and entered a valley, which I have named the Teleki Valley (see map, Pl. X); he followed this eastward until it suddenly bent northward and expanded into two great glacier-filled valleys, on the southern and south-western sides of the central peak. The high western wall of the Tyndall Glacier, the main western arête, the ridge which crosses the Teleki Valley, and the main peak together enclose a great depression, which Teleki regarded as the central crater of the volcano. Accordingly his companion, L. Ritter von Höhnel, in his description of the mountain, reports[1] the occurrence of a crater from 4 to $4\frac{1}{2}$ kilometres in diameter and from 200 to 300 metres in depth.

A third explanation of the geological character of Kenya was added by the next visitors to the mountain. In 1891 Mr. C. W. Hobley, the geologist who accompanied the British East Africa Company's expedition to Mount Kenya, climbed through the forests on the southern slopes up to the height of about 8600 feet, whence the peaks and spurs of the Alpine zone could be seen like a ridge along the northern sky-line. Accordingly, in the report of that expedition, Kenya is described[2] as 'more properly a mountain-chain, and not a single mountain, the chain or range stretching from west to east, commencing in the high Leikipia Plateau, and rising steadily until it culminates in the great double peak. Then comes the second large peak, with five or six other smaller ones; after these again, some lower mountains, all more or less connected, and finally an isolated hill is seen rising in the Barra to the east.'

As this report was published in August 1892, three months before I left England, I was accordingly doubtful when visiting Kenya in 1893 whether the mountain were a greatly denuded volcano, an existing crater, or a mountain-range running east and west.

Unfortunately my visit to Mount Kenya occurred in the latter part of the heaviest rainy season ever recorded in British East Africa,[3] and the wide extent of newly-fallen snow that covered nearly the whole of the uppermost part of the mountain obscured the geology of the Alpine zone. My stay on the mountain was curtailed, as it would have been unjust to expose my porters to the inclement weather then prevalent longer than was absolutely necessary. I had therefore to be content with the examination of such a section of the mountain as was sufficient to determine its geological structure and history. I examined the line from Ndoro at the western foot of the mountain to the level of the upper Alpine zone, at a point south-west of the summit: and then studied more in detail the

[1] 'Ostäquatorial-Afrika zwischen Pangani u. dem neuentdeckten Rudolf-See' Peterm. Mittheil. Ergänzbd. xxi. No. 99 (1890) pp. 7–8.

[2] E. Gedge, 'A Recent Exploration up the River Tana to Mount Kenia' Proc. R. Geogr. Soc. vol. xiv (1892) p. 527.

[3] The rainfall at Mombasa in 1893 was 64·17 inches as against 26·83 inches in 1892 and 37·96 inches in 1894: see '4th Rep. Climatology Africa' Rep. Brit. Assoc. 1895 (Ipswich) p. 486.

area between the western and southern arêtes and the adjacent part of the upper Alpine zone.

As the completion of a detailed report on the geological structure of British East Africa has been delayed, it seems advisable to publish it in instalments. I gladly express my indebtedness to Mr. C. W. Hobley, who kindly gave me the rock-specimens that he collected on Mount Kenya in 1891; and to Mr. G. T. Prior for much valuable assistance in the determination of some minerals in the rock-slides, and in consulting the fine collection of foreign rock-slides in the Mineralogical Department of the Natural History Museum. I am also indebted to Mr. Prior for kindly undertaking to see these pages through the press: a task which I am unable to fulfil myself, in consequence of my somewhat hurried departure for Australia.

II. Physical Geography of Mount Kenya.[1]

Mount Kenya consists of three zones: (1) a long forest-clad slope of volcanic ash, extending to a height of about 10,000 feet; (2) the open moors and valleys of the lower Alpine zone, covered by an open scrub of *Alchemilla Johnstoni* and a previously unrecorded species of arborescent *Erica*; and (3) the upper Alpine zone, formed of grassy meadows and valleys cut in volcanic ash below bluffs of coarse agglomerate. Above this upper zone is the steep rugged central peak, where the only vegetation consists of tufts of grass and *Helichrysum cymosum* with patches of lichen.

The altitude of Mount Kenya has been variously estimated as from 17,200 feet (Smith) up to 23,000 feet (Peters). L. von Höhnel's determination by triangulation from Ndoro made the height 19,029 feet, a figure which I have accepted, as my own observations roughly agreed with it.

The three main zones of Mount Kenya are characterized by different geological features. The long slope of the forest-belt consists in the main of volcanic ash, though the remains of secondary parasitic craters probably occur on it. The Alpine zone consists of coarser ash, agglomerates, and tuffs, interbedded with lava-flows and traversed by numerous dykes, with the remains of some secondary centres of eruption. The third zone, or central peak, consists of the plug which choked the central vent, and the beds of agglomerates and thick proximal ends of the great lava-flows.

III. Petrography.

The rocks of which Mount Kenya is built may be divided into four groups: (1) the rocks of the central core, (2) the dykes of the Alpine zone, (3) the lavas, and (4) the pyroclastic rocks.

[1] For a short account of the physiography of Mount Kenya, see 'The Glacial Geology of Mount Kenya' Quart. Journ. Geol. Soc. vol. l (1894) p. 515, and 'The Great Rift Valley' 1896, pp. 166 *et seqq.*

1. The Rocks of the Central Core.

The central peak of Kenya consists of a group of rock-pyramids, formed mainly of the lava that plugged the main vent. This rock is exposed on the main southern, south-western, and western arêtes.

The lowest exposure of any rock belonging to the central-core series was on the northern face of the valley below the snout of the Lewis Glacier. Unfortunately the field-relations of this rock were obscured by talus and snow. This rock (No. 496 [1]), which is somewhat gabbro-like in aspect, is coarsely crystalline, and consists of well-developed felspars, which are sometimes 15 mm. long and 3 mm. thick, separated by dark green minerals. The specific gravity is 2·6. Examined microscopically, the rock is seen to be an olivine-bearing nepheline-syenite. The rock is holocrystalline, hypidiomorphic, and coarse-grained. (Pl. XI, fig. 4.)

The main constituent is felspar, which occurs in large idiomorphic crystals twinned on the Carlsbad type, and in a mosaic of small crystals, many of which are also twinned on the Carlsbad type. The felspar is similar to that which occurs in the adjacent tuffs, and is probably in the main anorthoclase. This mineral was found in large isolated crystals in the tuffs of Mount Höhnel. The crystals are of the same character as those previously described by Mr. L. Fletcher & Prof. H. A. Miers [2]: they are described on p. 216. (See also Pl. XII, fig. 2, spec. No. 464.) The name anorthoclase is retained instead of natronmikroklin, which Brögger has shown holds priority; [3] but the latter, for English adoption, would require translation, and anorthoclase is more convenient for international use.

The second important constituent is nepheline, which occurs in very large prisms (3 to 4 mm. in diameter) and in small grains. The pyroxenes are bordered by a zone of ægyrine, which also occurs in scattered grains. The amphibole is deep brown in colour and has the pleochroism of barkevicite; but some of it, which is nearly opaque, Mr. Prior suggests may be allied to cossyrite. The rock contains a considerable amount of a bright yellow, strongly doubly-refractive, ferriferous olivine. Magnetite is scarce. Some isotropic mineral, probably sodalite, is also present.

The foregoing enumeration of the minerals shows that this rock is dominated by its high percentage of soda, and as it is the most deep-seated rock found on Mount Kenya it is natural to find the eruptive rocks characterized by soda-minerals.

Overlying this nepheline-syenite is a black glassy lava with numerous white phenocrysts of anorthoclase. The rock occurs as

[1] The numbers in parentheses are those affixed to my African rock-specimens, which will be presented to the Mineralogical Department of the Natural History Museum.

[2] Min. Mag. vol. vii (1887) pp. 10–11 & 131–132.

[3] 'Das Ganggefolge des Laurdalits' Die Eruptivgest. des Kristianiagebietes, pt. iii, in Vidensk. Skrift. pt. i (1897) No. 6, p. 12.

a massive core, which appears to have plugged the central vent of the mountain.

The rock of this plug (No. 499) consists of a black glassy groundmass with scattered phenocrysts of glassy felspar, which have rounded angles and lath-shaped sections, and range up to an inch in length. This rock occurs on the western arête above Two-Tarn Col, along the cliff that forms the right bank of the Lewis Glacier, and on the ridge rising northward from the col above the Lewis Glacier. Above these levels I could see no agglomerates, except a few unimportant patches, and these appeared to extend to the summit.

Under the microscope the large phenocrysts of felspar constitute the most striking feature of the rock; these, though seldom polysynthetically twinned, are no doubt anorthoclase.

The pyroxenic constituent is less abundant; it occurs in two forms. The sparsely scattered, small, very pale green phenocrysts, with rounded and sometimes even elliptical outlines and a high extinction-angle (over 30° from *c*) are augite. The second pyroxene is ægyrine, which occurs in small patches of green grains, while the black irregular grains which make the base appear dense are possibly altered ægyrine.

Olivine occurs in corroded crystals, often partly altered to serpentine. Apatite is present in well-developed prisms, included by all the other constituents of the rock.

The groundmass is crowded with felspar-microliths, small irregular pyroxene-granules, and innumerable small black granules which are possibly altered ægyrine. The rock does not show any pronounced fluxion-structure. (Pl. XI, fig. 1.)

The specimen (No. 499) upon which the foregoing description is based was collected on the ridge rising northward from the eastern end of the Lewis Glacier. Its specific gravity is 2·65.

To give a name to this rock is not easy. The excess of soda-minerals recalls the pantellerites, especially as Rosiwal[1] has provisionally applied that name to an allied rock from Southern Abyssinia. Mr. Prior, moreover, has called my attention to a slide of somewhat similar rock from the eastern flank of Montagna Grande (Pantelleria), which also contains porphyritic anorthoclase, a ferriferous olivine, and a pale green augite, included in a felspathic base full of minute irregular grains of pale green augite and opacite.

For the reasons, however, which are stated on pp. 213–214, it is unadvisable to include the Mount Kenya lavas among the pantellerites, and the name of k e n y t e s is accordingly proposed for them.

[1] 'Ueber Gesteine aus Schoa u. Assab' Denkschr. k. Akad. Wissensch. Wien, vol. lviii (1891) p. 518.

2. The Dyke-rocks.

The dykes of the Alpine zone of Mount Kenya fall into two categories: a series of phonolites and one of basalts and dolerites.

(*a*) The Phonolites.

As an example of the phonolites, we may take a dyke $4\frac{1}{2}$ feet wide which cuts vertically across the agglomerate on the western ridge of Mount Höhnel (No. 456). The rock is dark greenish, fine-grained, and somewhat fissile. The specific gravity of a specimen from the middle of the dyke is 2·6. Under the microscope the rock is seen to be composed mainly of felspar, in small lath-shaped crystals, with well-marked fluxional arrangement. The most conspicuous mineral is nepheline, which is abundant and stands out with remarkable clearness; the crystals are fresh, and the larger prisms measure from ·3 to ·4 mm. in length. The pyroxenic constituent is ægyrine, which occurs as plates with frayed ends and as crystals with regular hexagonal sections; the smaller ægyrines are often clustered like a framework around the nephelines. (Pl. XI, fig. 5.)

Mr. Prior has shown me a slide of a phonolite from Risca (Grand Canary), which is almost identical with this rock, and a second slide from Chasna (Teneriffe), in which the resemblance, though less complete, is close.

The most striking feature of this dyke is its selvage, which has the characters of a glassy basalt (No. 457). It consists of a black basic glass in which are numerous circular vesicles and small lath-shaped crystals of plagioclase: the larger crystals show twinning on the albite-type, with symmetrical extinction in alternate lamellæ of about 35°, and may consequently be referred to labradorite.[1] Olivine is abundant, occurring in small idiomorphic crystals. The glassy groundmass does not gelatinize when treated with cold hydrochloric acid. (Pl. XI, fig. 6.)

This dyke is therefore compound, being made up of a central sheet of phonolite bounded by basaltic selvages.

As this phonolite is a dyke-rock, it may seem advisable to adopt for it the name tinguaite; but in his original definition of that rock Rosenbusch[2] laid stress on the absence of fluidal structure, whereas the dyke from Mount Höhnel shows well-developed fluxion-structure, which is absent from the phonolitic flows of Kenya. In 1896, however, Rosenbusch[3] admitted fluidal structure in tinguaites, and based the distinction between them and phonolite on the aplitic instead of trachytic structure. But as the Mount Kenya dykes are as trachytic as the flows, and as the two types are microscopically indistinguishable, it seems advisable to accept the name phonolite for both.

[1] The identification of this plagioclase has been kindly confirmed by Mr. Prior.

[2] 'Mikroskop. Physiogr.' 2nd ed. vol. ii (1887) p. 628.

[3] *Ibid.* 3rd ed. vol. ii (1896) pp. 479–480. Brögger has described a fluidal tinguaite from Lyseböfjord, north of Laurvik, in 'Die Gesteine der Grorudit-Tinguait Serie' Die Eruptivgest. des Kristianiagebietes, pt. i, in Vidensk. Skrift. pt. i (1894) No. 4, p. 117.

(*b*) The Basic Dykes.

The dykes of the second group are more basic in character, and range from a basalt with a little olivine to a coarsely crystalline dolerite rich in olivine.

The rock of this series, which, judging from its specific gravity, is the least basic, is a dark brown, compact basalt, collected by Mr. C. W. Hobley during the British East Africa Company's expedition to Mount Kenya in 1891. It was obtained in a ravine at the height of about 7000 feet on the southern slope of the mountain. The specific gravity is 2·74. Under the microscope the rock appears as a felted mass of lath-shaped plagioclases, which are cut across in all directions. Some platy felspars are also present. Granules of a pale brown to greyish pyroxene and of olivine are abundant; and numerous very thin acicular crystals, which Mr. Prior refers to apatite, traverse the plagioclases.

The basic dykes of the Teleki Valley district have a higher specific gravity, and contain more olivine and magnetite than the specimen collected by Mr. Hobley. These more basic dykes are well exposed near the snout of the Lewis Glacier, and are of considerable width; in the centre they are coarsely crystalline, and may be called olivine-dolerites. The dykes which have yielded specimens 510 & 511 may be taken as types of this group.

No. 510, from the centre of a dyke below the snout of the Lewis Glacier, consists largely of plagioclase-laths: these, from their high extinction-angle, may be referred to labradorite. Augite is abundant, in nests of small prismatic crystals and in rounded phenocrysts. Olivine in small altered crystals is also plentiful. The specific gravity of the rock is 2·8.

A larger dyke from the same locality (No. 511) is a black rock weathering dark brown; it contains numerous tabular crystals of plagioclase, roughly parallel in arrangement, and large crystals of black pyroxene which are recognizable in hand-specimens. The specific gravity is 2·97. Examined under the microscope, the plagioclase is seen to occur in two forms. The olivine is idiomorphic. The augite is titaniferous, with a pleochroic outer zone. This rock is the most basic of the Kenya dykes from which specimens have been collected so far.

3. The Lavas.

The Mount Kenya lavas belong to three groups:—

(*a*) The Kenytes or Lavas of the Nepheline-syenite Series.

At various points on the south-western flanks of the central peak of Mount Kenya are a series of flat-topped, massive crags, which can be recognized from Laikipia. These crags are remnants of the greatest series of lava-flows that came from the central vent of Kenya. The rocks which form these crags are well exposed, for instance, on the Lewis Col and on the Teleki Ridge, where they rest upon beds of

agglomerate and tuff, which in places also cover them. The typical representatives of this lava are rhyolitic in aspect, earthy-looking, vary from light red to pale brown, and show very conspicuous fluxion-structure.

Examined microscopically the rocks of this type appear to consist of a brown, light green, and dark green glassy base, with numerous opacite-granules and felspar-microliths, and large corroded phenocrysts of anorthoclase. The matrix is indeterminable microscopically, but when treated with cold acid it becomes gelatinous and yields abundant crystals of common salt; we may, therefore, safely infer that the glassy matrix is extremely rich in soda, and would probably have yielded much nepheline had it crystallized. The rock represents the flows from the plug of solid lava that choked the main vent. The specific gravity of the variety (No. 500) nearest the lava of the central plug is 2·62, while in flows farther away from the central core, at the Lewis Col and on the Teleki Ridge, the specific gravity sinks to 2·5.

The aspect of the rock is very variable; as examples we may take the following types:—

No. 500, from north of the Lewis Col. Specific gravity 2·62. The rock has a light-green matrix and an indefinite fluxion-structure; the phenocrysts of anorthoclase are large, but not crowded; the groundmass is dense from the abundant pale green microliths, which Mr. Prior, from their optical characters, refers to ægyrine.

No. 507, from the Lewis Col itself. Specific gravity 2·5. A coarse, rhyolitic-looking, reddish lava, with well-developed fluxion-structure round the anorthoclase-phenocrysts, which contain inclusions of the glassy base.

No. 508. Dark green, almost black rock, with small anorthoclase-phenocrysts in a dense base of minute felspar-microliths, magnetite- and ægyrine-grains. The felspars are often twinned on the Carlsbad type. (Pl. XI, fig. 3.)

No. 452 is a specimen from a flow of black lava similar to the last, but including a bomb of a reddish rock. (The latter is closely allied to No. 519, the reddish base probably resulting from the alteration of a basic glass.) The black lava contains many phenocrysts of anorthoclase showing well-developed twin lamellæ. The glassy base includes ægyrine and some ill-defined mineral, which is probably ægyrine undergoing alteration into opacite. An imperfect spherulitic structure occurs in places. Mr. Prior notes that some of the phenocrysts are partly replaced by an aggregate of lath-shaped felspars and pale-green augite, similar to the pseudomorphs after felspar described by Brögger [1] in grorudite. Mr. Prior also remarks the resemblance of this rock to a specimen in the Natural History Museum from the west side of the Val di Monastero, Costa di Zichidi (Pantelleria).

No. 519. One of the most interesting rocks in this kenyte-series is a black porphyritic pitchstone, which occurs in Phonolite Cwm,

[1] 'Die Gesteine der Grorudit-Tinguait Serie' Eruptivgest. des Kristianiagebietes, pt. i, in Vidensk. Skrift. pt. i (1894) No. 4, p. 15.

east-north-east of Mount Höhnel, and in the agglomerates of that district. The rock consists of large anorthoclase-crystals embedded in a black tachylytoid glass, which is apparently more basic than in pantellerites. Examined under the microscope the glass appears deep brown, and contains some vesicles. The anorthoclase-phenocrysts are large, and zonally constructed; they include apatites and brown-glass inclusions. Some cleavage-fragments have been measured by Mr. Prior, who determined the extinction on *b* as 8° to 9°, and on *c* as nearly straight. Olivine occurs in corroded phenocrysts. The specific gravity of the rock, measured from a large block which may contain a few vesicles, is 2·5. (Pl. XI, fig. 2.)

To find a suitable name for these rocks is not easy. In the field I called them rhyolites, but they differ from ordinary rhyolites by the absence of quartz and by their great excess of soda. Accordingly, it is natural to compare them with the rich soda-bearing rhyolites of Pantelleria, especially as the porphyritic pichstone is practically identical with a rock from Shoa, in Southern Abyssinia, described by Rosiwal,[1] who named it 'vitrophyrischer augit-trachyt (pantellerit).' But this identification has been denied by Rosenbusch, who maintains that a rock composed of anorthoclase-phenocrysts in a glassy groundmass rich in soda is not necessarily a pantellerite.

According to Rosenbusch's definition, 'pantellerites are characterized by the absolute predominance of the alkali-felspar, the total absence of the lime-soda felspar, the development of ænigmatite [cossyrite], diopside, ægyrine, and arfvedsonitic amphibole as the colouring constituents with the almost absolute suppression of mica; by the absence of magnetite, the rarity of quartz of the first generation, the predominance of the glassy and microcrystalline structures and the extreme rarity of microfelsitic structure; and by the abundant formation of the colouring constituents in the eruptive period.'[2] This definition certainly does not describe accurately the Mount Kenya lavas. They contain neither ænigmatite nor arfvedsonitic amphibole, nor, in fact, any other amphibole. The positive characters also are different: olivine is fairly abundant in some slides; the colour of the rock is dark sepia-brown, red, or grey, rarely green, and one variety occurs with a tachylytoid groundmass.

Rosenbusch objects that the Shoan rock described by Rosiwal should be referred to pantellerite because 'of its colour (brown to grey) and its glassy, felsitic habit.' 'The anorthoclase alone,' he continues, 'does not postulate the pantellerite character; for that are needed also the alkali-pyroxene and the alkali-amphibole, and the remaining above-stated characters.'

To include these Mount Kenya lavas in pantellerite would necessitate a complete redefinition of that term. The only definition of pantellerite that would include the type-rock and these

[1] 'Ueber Gesteine aus Schoa u. Assab' Denkschr. k. Akad. Wissensch. Wien, vol. lviii (1891) p. 518.

[2] 'Mikroskop. Physiogr.' 3rd ed. vol. ii (1896) p. 612.

lavas would be limited to the character that it is a lava with a glassy base containing phenocrysts of anorthoclase; and that statement as a definition of pantellerite Rosenbusch has emphatically repudiated. No doubt the kenytes and pantellerites are closely related, but I do not feel justified, on the evidence at present available, in radically altering Rosenbusch's diagnosis. It seems therefore advisable to give to these East African lavas the new name of kenyte, from the mountain where they reach their highest development.

The kenytes may be defined as liparitic representatives of an olivine-bearing nepheline-syenite, consisting of anorthoclase-phenocrysts, with or without some augite- and olivine-phenocrysts, and a glassy or hyalopilitic groundmass, which varies in colour from greyish-green to a deep sepia-brown. Ægyrine, if present, occurs in small granules; ænigmatite and quartz are absent.

The kenytes are most nearly allied to the pantellerites, but are probably as a rule more basic. Taking the average of the five analyses of pantellerites quoted by Prof. Lœwinson-Lessing,[1] and the formulæ which he has calculated from them, pantellerite agrees more nearly with the chemical composition of dacites than with that of nepheline-syenites:—

	RO.	R_2O_3.	SiO_2.	Acidity.
Pantellerites	2·34	1·40	11·48	3·54
Dacites	2·23	1·74	11·24	3·02
Trachytes	2·52	1·96	10·26	2·42
Nepheline-syenites	2·69	2·31	9·25	1·91

Prof. Zirkel[2] quotes an analysis of a dacite with a higher soda-percentage than is recorded for any of the five analyses of pantellerites. The rock is from Zovon, west of Teolo, in the Euganean Hills: it is described by Zirkel as having a 'light-coloured groundmass, with many large oligoclases from 3 to 4 lines long, also biotite and hornblende; much magnetite ... a little quartz in small druses; specific gravity 2·593.' From the analysis it appears not improbable that this Teolo rock should be included among the pantellerites, and that the mineral determined as oligoclase is really anorthoclase:—

	Dacite.	Pantellerite.
SiO_2 Silica	67·98	68·33
Al_2O_3 Alumina	13·05	10·94
FeO Ferrous Oxide	......	3·74
Fe_2O_3 Ferric Oxide	5·69	5·41
CaO Lime	1·63	1·36
MgO Magnesia	0·14	0·16
K_2O Potash	3·23	4·08
Na_2O Soda	7·96	7·09

But if this Teolo dacite be a pantellerite, the fact that it has been included among the dacites illustrates the chemical similarity of these rocks.

[1] 'Stud. über die Eruptivgest.' Congrès Géol. Internat. Compt. Rend. sess. vii, St. Petersb. (1897) pp. 449, 451, 453.

[2] 'Lehrbuch d. Petrogr.' 2nd ed. vol. ii (1894) pp. 575, 582.

(*b*) The Phonolites.

The lavas of the phonolite-group are less conspicuous than the kenytes, as they form the lower slopes of the upper Alpine valleys, which were obscured by moraine and snow. The phonolites may be seen on both banks of the Teleki Valley, and one of the best exposures is on the lower western slopes of Mount Höhnel.

The rock (No. 490) in hand-specimens is dark, speckled, and greyish-green, and is very fissile. In the centre of the flow it is compact, and under the microscope resembles more closely a dyke than a flow. This rock consists of much the same material as the dyke on the western ridge of Mount Höhnel. Its structure is trachytic; the groundmass includes abundant, small, lath-shaped felspars, which are irregular in arrangement, and often occur in radial groups. The pyroxenes are small, and consist of ægyrine in needles and short crystals, often arranged in moss-like aggregates. Nepheline is not very abundant, but occurs in larger crystals than the other constituents. (Pl. XII, fig. 1.)

(*c*) The Basalts.

The basalt-flows of Mount Kenya occur in two main areas. There is one series of very fissile olivine-basalts which occur in the forest-zone. Mr. Hobley collected on the southern slopes a specimen of a very vesicular basalt composed mainly of lath-shaped plagioclases, with a well-marked fluxion-structure around the empty vesicles. The groundmass is very dense, from the abundance of small crystalline granules and grains of magnetite. Olivine occurs both as granules and as small, corroded, rounded crystals.

On the western foot of Kenya a fissile olivine-basalt is one of the commonest constituents of the tuffs and gravels; and, as the pebbles appear to have travelled a shorter distance than the kenytes, it is probable that some dykes or flows of this rock occur in the forest-zone. These fissile basalts have a specific gravity of 2·7.

The second set of basaltic lavas occur in the neighbourhood of Mount Höhnel and the Teleki Valley. The best example of this rock forms crags of columnar basalt, wherein the columns are some 20 feet high and are often curved. The rock in the upper and lower surfaces of the flow is massive, and the lower belt contains a few inclusions of the kenytes.

No. 517 is a heavy, black, fine-grained basalt of specific gravity 3·09; the section shows no phenocrysts of plagioclase. Olivine is abundant, and occurs both in idiomorphic crystals and in rounded inclusions, which, though corroded, are not serpentinized; in one case the olivine forms a mere shell surrounding an included fragment of the groundmass. The groundmass consists of microliths of plagioclase and grains of pyroxene, olivine, and magnetite.

The rock in an adjacent part of this flow is coarser in grain, and there the chief minerals are olivine, plagioclase, and titaniferous augite, while magnetite occurs in large skeleton-crystals.

4. The Pyroclastic Rocks.

The fragmentary volcanic rocks of Mount Kenya consist of a broad zone of volcanic ash, which forms the main foot-slope of the mountain, extending on the west from Ndoro (at an altitude of 7100 feet) to the lower edge of the Alpine zone (alt. 10,100 feet). In the lower part of this foot-slope occur beds of tuff and lava-gravel, in which pebbles of fissile basalt predominate.

In the Alpine zone the most prominent fragmentary rocks are beds of coarse agglomerate, well exposed as rough crags and pinnacles. The materials of these agglomerates are mainly coarse blocks of kenyte and phonolite.

The tuffs are best developed in the upper Alpine zone, where they are well exposed on the cliffs of Mount Höhnel, a section of which shows them interbedded with ash and flows of kenyte overlying the main phonolitic beds at the base (fig. 1, p. 217). The tuffs are often vesicular, with the cavities lined by zeolites. The most interesting feature of these tuffs is the occurrence of large crystals of anorthoclase, which have been kindly examined by Mr. Prior, who reports as follows:—'The crystals are apparently simple, with the faces *b* (010), *m* (110), M ($1\bar{1}0$), *c* (001), with *x* ($\bar{1}01$), or in some crystals *y* ($\bar{2}01$), all well developed. The cleavage-angle *b c*, measured by the reflecting goniometer, did not differ more than 2′ from 90°. The extinctions measured on cleavage-flakes are

on *b*, 7° to 8°, obtuse positive bisectrix;
on *c*, 1° to 2°, very fine twin lamellæ.

The material gives a strong sodium-flame.'

IV. The Stratigraphy of Mount Kenya.

Turning from the petrography of the rocks to their stratigraphical arrangement, we find that this is simple. The nepheline-syenite to the north-west of the snout of the Lewis Glacier is the most deep-seated holocrystalline rock on the mountain, and doubtless represents the original magma of the volcanic series. This rock probably passes upward into the massive core of porphyritic kenyte which forms the central peak of the mountain; but no actual passage could be traced, and it is conceivable that the nepheline-syenite may be an intrusion into the kenyte-plug. (See fig. 2, p. 217.)

The upper Alpine zone, with its coarse agglomerates and radial dykes, no doubt occupies the site of the crater-walls of the old volcano, though the crater-edges must have been some thousands of feet above the present height of this zone. The Alpine agglomerates are traversed by numerous vertical dykes of olivine-basalt and olivine-dolerite, and some flows of olivine-basalt also occur in it.

The main lava-flows of Kenya are best exposed in the upper Alpine zone. They slope at a dip of usually 8° to 15° from the central plug. So far as my observations extended, the dip of

Fig 1.—*Diagrammatic section from the summit of Mount Kenya to the south of Mount Höhnel.*

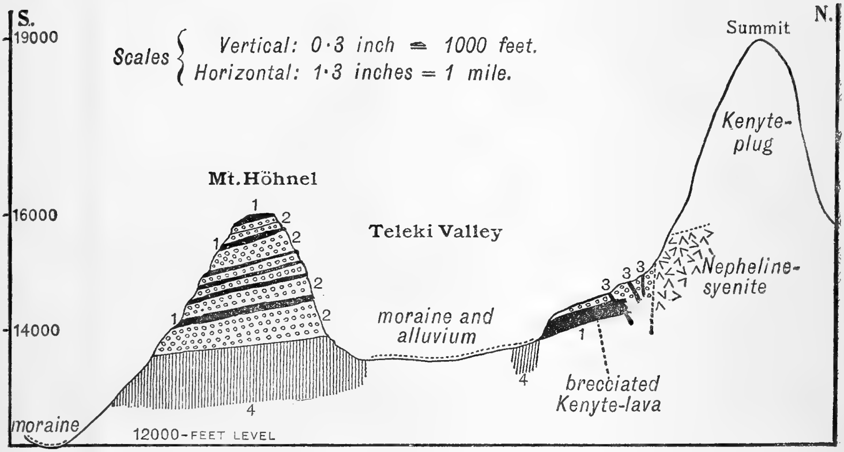
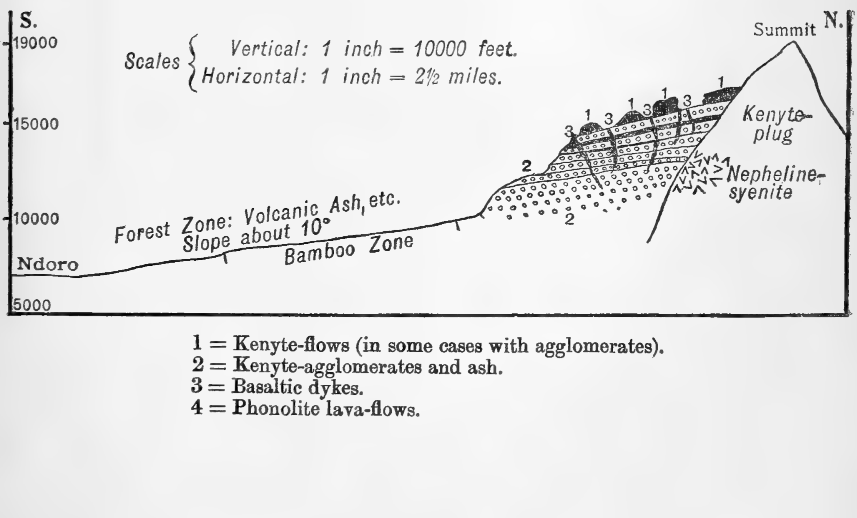


Fig. 2.—*Diagrammatic section through the south-western part of Mount Kenya.*



1 = Kenyte-flows (in some cases with agglomerates).
2 = Kenyte-agglomerates and ash.
3 = Basaltic dykes.
4 = Phonolite lava-flows.

these lavas is quaquaversal; thus on the eastern ridge of the Hobley Valley the rocks dip south-eastward; on the Lewis Col and its main southern ridge they dip southward; on the flanks of the Teleki Valley they dip south-westward; and on the north of the Thomson Valley (the second valley northward from the Teleki Valley) they dip north-westward.

As an illustration of the arrangement of the lava-series in the Teleki Valley area, we may consider the section exposed on the western arête and face of Mount Höhnel. At the base are greenish fissile phonolites, which form the slopes around Lake Höhnel, the lower part of both flanks of the Teleki Valley and of Phonolite Cwm, and the floor of the col at the lower end of the western ridge of Mount Höhnel. This phonolite is not well exposed, for the rock is easily denuded and weathers into smooth slopes, which are mostly covered by talus, snow, and moraine-débris. Ascending Mount Höhnel by the western ridge we find the following sequence. Next above the phonolite comes:

2. A thick flow of porphyritic kenyte wherein the anorthoclase-phenocrysts are smaller and more crowded, and the groundmass is of a brighter red than in the usual variety;

3. A thick bed of tuff, partly vesicular, and enclosing large crystals of anorthoclase;

4. A flow of kenyte;

5. Coarse kenyte-agglomerate (no basalt-pebbles could be found in it);

6 (in 5). A vertical compound dyke of phonolite with basic selvages; the dyke is 4½ feet wide, and stands out as a wall 3 feet high;

7. Brown and buff volcanic ash over the agglomerate (5), dipping 8° south-westward;

8. Flow of black kenyte, including red porphyritic bombs;

9. Alternations of coarse ash and agglomerate, weathering into crags (including the 'Janda Pinnacle');

10. Porphyritic kenyte, with a dull pinkish groundmass;

11. Thin kenyte-flows interstratified with tuff; and

12. A coarse flow of porphyritic kenyte capping the summit.

The total thickness of the foregoing series (2 to 12 inclusive) is about 1600 feet.

V. The Geological History of Mount Kenya.

Mount Kenya accordingly consists of a very ancient, denuded volcano, which is built up of rocks belonging to three petrographical types: (1) an olivine-bearing nepheline-syenite, with its kenytes; (2) the phonolite-series of dykes and flows; and (3) the olivine-basalt series.

At first, I was inclined to believe that the basalts were the oldest members of the series: for Mr. C. W. Hobley had given me in Mombasa a specimen of a vesicular basalt from the edge of the forest-zone of the southern slopes of Kenya; and, on the day after we reached the Alpine zone, I found blocks of an apparently tachylytic lava in the agglomerates. It accordingly seemed probable that

Kenya had begun with the ejection of basic materials, and that the phonolitic series was the more recent. This arrangement would have been in accordance with the general rule of ejection in order of decreasing basicity. In Bohemia, that classic land of phonolites, the sequence of the Aquitanian (Upper Oligocene) volcanic series, as determined by Hibsch, begins with nepheline- and plagioclase-basalts, which are followed by tephrites, and these in turn by phonolites, and finally come the trachytes.[1]

But further field-evidence refuted the idea that the basalts were earlier than the more acid kenytes. The supposed tachylyte in the agglomerates, in spite of its basic aspect both in hand-specimens and under the microscope, proved to be of too low a specific gravity, and must be regarded as a pitchstone; and the field-evidence in the Teleki Valley showed that the olivine-basalt dykes are intrusive into the kenyte-series, while the olivine-basalt flows must be later, as they include some fragments of the kenytes.

The oldest lavas found on Mount Kenya are the phonolites, flows of which occur below the great kenyte-series of Mount Höhnel and in the Teleki Valley. But there does not appear to be any sharp separation in age between the phonolites and the kenytes, since the former in the Mount Höhnel sequence are immediately covered by the kenyte-tuffs, which are themselves traversed by phonolite-dykes. These phonolite-dykes are darker and more basic than the phonolite-flows, but the differences are slight.

The phonolites and kenytes appear, therefore, to have overlapped, and they probably represent two closely-allied types produced by differentiation from the same rich soda-bearing magma.

The last stage in the volcanic history of the Teleki Valley quadrant of Mount Kenya is represented by the olivine-basalts. The basalt- and dolerite-dykes cut across the kenytes, and are in no place, so far as I saw, cut by the nepheline-bearing dykes. The basalts do not seem to reach the surface higher than the upper Alpine zone; Mr. Hobley found them on the edge of the southern forest-zone, at the height of 8600 feet, and the basalts probably reached the surface from a belt of secondary craters in the Alpine zone on the margins of the kenyte-plug which choked up the original vent. Such a centre of eruption probably occurred near Mount Höhnel, for flows of fissile and columnar olivine-basalts occur around that peak.

It cannot be affirmed, however, that the whole of the Kenya basalts are later than the phonolite-kenyte series, for the fissile

[1] See his 'Geologie' (1885) p. 319, for the age of the series; for the sequence, see his 'Ueber die Eruptionsfolge im böhmischen Mittelgebirge' Sitzber. deutsch. Naturw. Med. Ver. Böhm. Lotos (1897) No. 1. It is just possible that the phonolite at the western foot of Mount Höhnel may be an intrusive sheet. In the field I regarded it as a contemporaneous lava-flow, and only collected one specimen from the middle; but microscopically the rock has rather the aspect of a dyke, and it is possible that the apparently vesicular upper surface may have been due to the incorporation of tuffs.

basalts of the lower slopes, which form so large a proportion of the gravels near Ndoro, may possibly be older than the basalts of the upper Alpine zone. Petrographically the two basalts agree, but the dense jungles of the forest-zone prevent any definite correlation by stratigraphical evidence. It might be suggested, therefore, that the basalts of the lower forest-zone belong to an earlier series of basic eruptions, which were pierced by the core of nepheline-syenite, and covered by the central pile of the kenyte-series; after which a minor basaltic series closed the volcanic history of the mountain. Cases of such subsidiary recurrence of basalt are known; thus among the Kainozoic volcanoes of Scotland Sir Archibald Geikie[1] has remarked that 'in the case of the Tertiary volcanic series [of Scotland] there is evidence that after the acid protrusions a final uprise of basic material occurred.' The basalts of Pantelleria may be another illustration of this tendency. But, other than the general rule of eruptive sequence, I know of nothing to suggest the occurrence on Mount Kenya of a double series of basalts; and at present there is no evidence of any basalts on the mountain earlier than the kenyte-series. Though the basalts whose relative age is known are younger than the phonolites and kenytes, it does not seem necessary to assume any great lapse of age between them; for it is possible that all the lavas represented in the Teleki Valley quadrant may belong to one series. They may all have resulted by differentiation from the olivine-anorthoclase-nepheline-syenite magma, from which were erupted first phonolites, then kenytes, and finally olivine-basalts.

In Pantelleria, though no definite passage has been described from the pantellerites to the basalts, the sequence as determined by E. Fœrstner[2] agrees with that of Mount Kenya; for it began with phonolites, which were followed by pantellerites, and it closed with basalts. In the nepheline-syenite area of Christiania, as described by Brögger, the passage in the dyke-series from tinguaites rich in nepheline to sölvsbergites free from nepheline, and the similar passage in the deep-seated rocks from the nepheline-bearing foyaites to the nephelineless hedrumite are comparable to the passage from the nepheline-syenites and phonolites of Mount Kenya to the kenytes in which nepheline has not been developed.

VI. Kenya and Kilima Njaro.

The position of Mount Kenya in the East African volcanic series can be more conveniently considered after a description of the adjacent volcanic areas; but it is advisable to include some comparison of the mountain with the other great extinct East African volcano, Kilima Njaro. Unfortunately, however, the exact geological history of Kilima Njaro has not yet been determined. Extensive rock-collections have been made there and carefully

[1] 'Ancient Volcanoes of Great Britain' vol. ii (1897) p. 477.

[2] 'Nota preliminare sulla Geologia dell' Isola di Pantelleria' Boll. Com. Geol. Ital. vol. xii (1881) pp. 539–544.

studied, ranging from Gustav Rose [1] and J. Roth's [2] descriptions of the collection of von der Decken, and Prof. Bonney's [3] account of the specimens obtained by Sir H. H. Johnston, down to the more recent and detailed descriptions of J. S. Hyland,[4] A. C. Tenne,[5] and A. Rosiwal,[6] but the stratigraphical relations of the rocks are uncertain. Thus, as Baron E. Stromer von Reichenbach [7] has remarked, 'we are not yet able to decide further as to the character of the rocks of Kilima Njaro, for the positions of its separate points of eruption, its lava-streams, etc., have not yet been systematically investigated.'

So far as concerns the evidence of the Teleki Valley quadrant, Mount Kenya has had a shorter geological history and is built up of a narrower range of rock-types than Kilima Njaro. The rocks of the latter range from limburgites to obsidians, from peridotites to trachytes.[8] On Mount Kenya I found nothing so basic as a limburgite, or so acid as a trachyte: that mountain probably represents, therefore, only a small part of the long volcanic history of Kilima Njaro. In point of structure Mount Kenya is now in the condition of the Mawenzi peak of Kilima Njaro; and, according to Mr. Prior, the two peaks probably correspond petrographically, for he finds that rock-specimens from Mawenzi in the Natural History Museum present characters, both macroscopic and microscopic, very similar to those of the kenyte-lavas.

VII. Summary of Conclusions.

(i) Mount Kenya is an ancient, much-eroded volcano; the highest peak is formed of the rocks of the central plug; the site of the crater-walls is marked by the agglomerates, ashes, and tuffs of the Alpine zone.

(ii) The main lava-series is formed of kenytes, rocks allied to pantellerites, but of a somewhat more basic type.

(iii) The lowest exposure of the central core is an olivine-bearing nepheline-syenite.

(iv) The lava-sequence is: firstly, phonolite; secondly, kenytes; and finally, olivine-basalts.

[1] 'Beschreibung der von Herrn von der Decken gesandten Gebirgsarten aus Ost-Afrika, grösstentheils vom Fusse des Kilimandjaro' Zeitschr. Allgem. Erdk. Berlin, n. s. vol. xiv (1863) p. 245.

[2] 'Beschreibung der zweiten Reihe der von Herrn von der Decken aus der Gegend des Kilimandjaro mitgebrachten Gebirgsarten' *ibid.* n. s. vol. xv (1863) pp. 543–45.

[3] 'Report on the Rocks collected by H. H. Johnston from the upper part of the Kilima-Ndjaro Massif' Rep. Brit. Assoc. 1885 (Aberdeen) pp. 682–85.

[4] 'Ueber die Gesteine des Kilimandscharo u. dessen Umgebung' Tscherm. Min. Petr. Mitth. vol. x (1889) pp. 203–70 & pl. vii.

[5] 'Die Gesteine des Kilimandscharo-Gebietes' in H. Meyer's 'Ostafrikanische Gletscherfahrten' (1890) pp. 305–10; see also Calder's transl. London 1891, pp. 346–51.

[6] 'Ueber Gesteine aus dem Gebiete zwischen Usambara u. dem Stefanie-See' Denkschr. k. Akad. Wissensch. Wien, vol. lviii (1891) pp. 483–87.

[7] 'Geol. deutsch. Schutzgeb. in Afrika' Munich 1896, p. 55.

[8] F. H. Hatch, 'On a Hornblende-Hypersthene-Peridotite from Losilwa, a low hill in Taveta District, at the S. foot of Kilimandjaro, E. Africa' Geol Mag. 1888, pp. 257–60.

EXPLANATION OF PLATES X, XI, & XII (*pars*).

Plate X.

Geological sketch-map of the south-western quadrant of the Central Peak and Upper Alpine Zone of Mount Kenya, on the scale of 1 inch to the mile.

Plate XI.

Microscope-sections of igneous rocks from Mount Kenya.

Fig. 1. Kenyte of the plug (No. 499, p. 209). The section shows large corroded anorthoclase-phenocrysts on the right, an altered olivine in the centre, a rounded broken crystal of pale green augite on the left, with one or two prisms of apatite and dark patches of ægyrine-grains. × 12.

2. Kenyte with tachylytic base (No. 519, p. 213). The large corroded crystal at the top is anorthoclase; the rounded crystal below it is yellow olivine. × 10.

3. Kenyte-lava (No. 508, p. 212). The dense base is crowded with ægyrine-grains and minute felspar-microliths showing flow-structure: throughout the slide are rounded patches of a coarser-grained aggregate of felspar-laths and ægyrine: the felspar-phenocrysts are small (one is shown in the section to the left of the central patch), and in many cases have suffered almost total reabsorption. × 12.

4. Nepheline-syenite of the Central Core (No. 496, p. 208). In the centre of the section is an irregular crystal of barkevicitic hornblende: the colourless mineral with a dark inclusion above the hornblende is nepheline, forming part of a mosaic of felspars and nepheline, finer-grained than the rest of the section. Below the hornblende-phenocryst are large felspars in Carlsbad twins. On the left, and surrounded by opacite, are crystals of pale purplish augite fringed by a zone of ægyrine. × 20.

5. Phonolite dyke-rock (No. 456, p. 210). The dark phenocrysts are ægyrine, which also occurs in needles interspersed between the felspar-laths and in dense patches round the clear hexagonal and rectangular sections of nepheline. × 20.

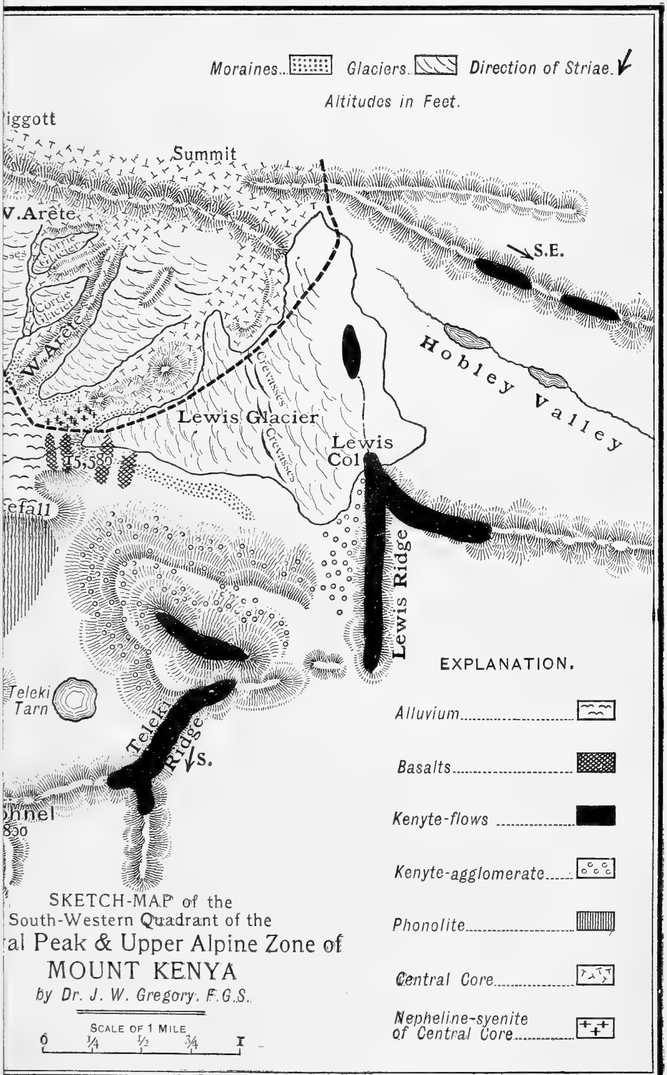
6. Glassy basalt forming a composite dyke with phonolite (No. 457, p. 210). The section shows clear, sharply-defined laths of labradorite, and numerous small rhombic and hexagonal sections of olivine, with a few augite-prisms, in a dense glassy base crowded with magnetite-grains. × 20.

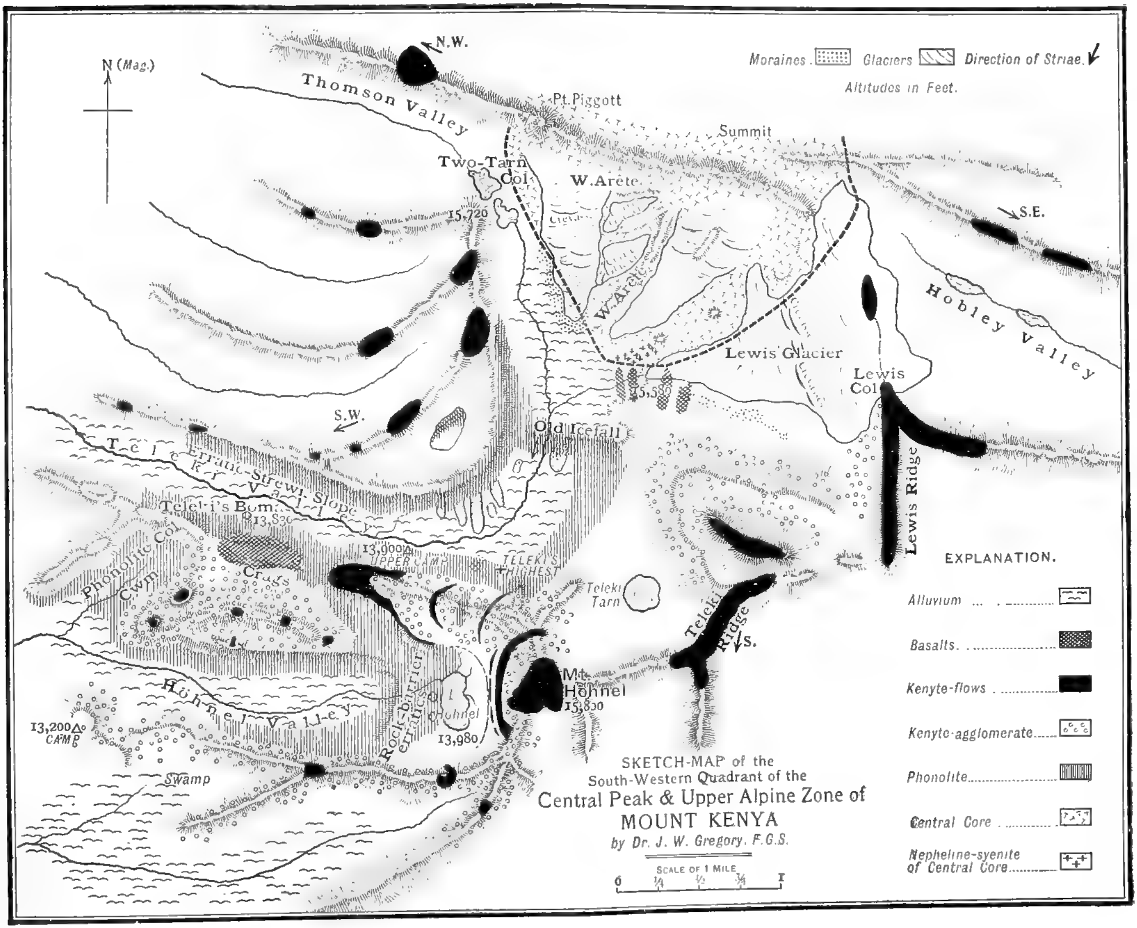
Plate XII (*pars*).

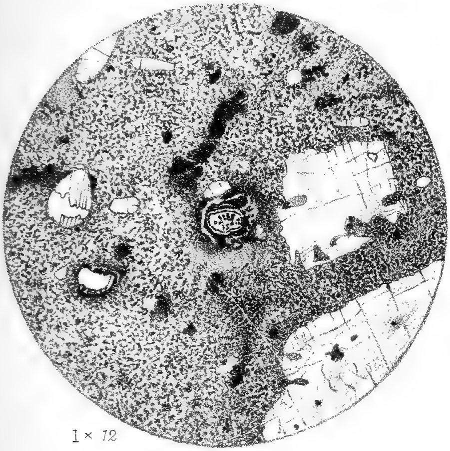
Fig. 1. Phonolite-flow (No. 490, p. 215) The section shows the same mineral constituents as Pl. XI, fig. 5, but the felspar-laths of the base do not exhibit any well-marked flow-structure. × 12.

2. Kenyte from Mount Höhnel (No. 464, p. 217). The section shows the least glassy specimen of kenyte, as seen between crossed nicols. The large phenocrysts exhibiting very fine twin striations are anorthoclase. The clear-cut octagonal section showing a nearly rectangular cleavage is almost colourless augite (diopside). The small, sharply-defined hexagonal sections are apatite. The base, which is rather dense with opacite-grains, contains numerous lath-shaped felspars. × 12.

Quart. Journ. Geol. Soc. Vol. LVI, Pl. X.



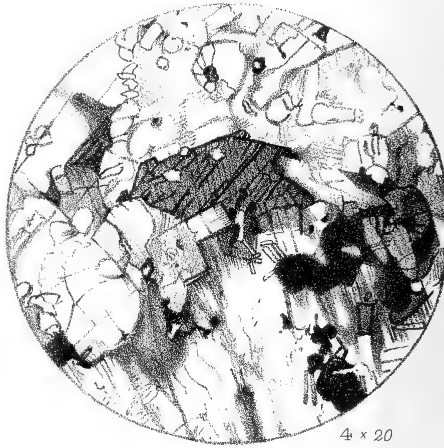

N (Mag.)
N.W.
Thomson Valley
Pt. Piggott
Summit
Two-Tarn Col
W. Arête
15,720
S.E.
W. Arête
Hobley Valley
Lewis Glacier
Lewis Col
15,580
S.W.
Old Icefall
Tele Erratic-Strewn Slope
Teleki Valley
Teleki's Boma
13,830
13,900
UPPER CAMP
TELEKI'S HIGHEST
Crags
Phonolite Col
Cwm
Teleki Tarn
Lewis Ridge
Teleki Ridge
S.
Mt. Höhnel
15,800
Höhnel Valley
Rock-barrier erratics
13,980
13,200
CAMP
Swamp
Moraines
Glaciers
Direction of Striae.
Altitudes in Feet.
EXPLANATION.
Alluvium
Basalts.
Kenyte-flows
Kenyte-agglomerate
Phonolite
Central Core
Nepheline-syenite of Central Core
SKETCH-MAP of the South-Western Quadrant of the Central Peak & Upper Alpine Zone of MOUNT KENYA
by Dr. J. W. Gregory, F.G.S.
SCALE OF 1 MILE
0 1/4 1/2 3/4 1



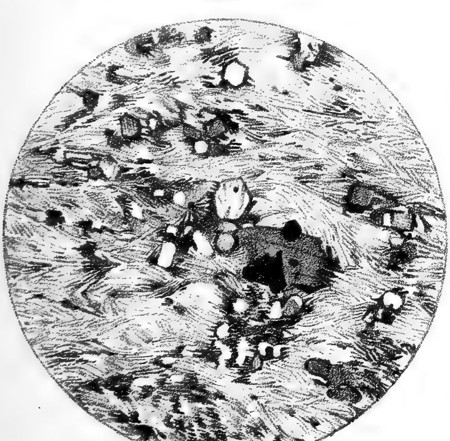
1 × 12

2 × 10

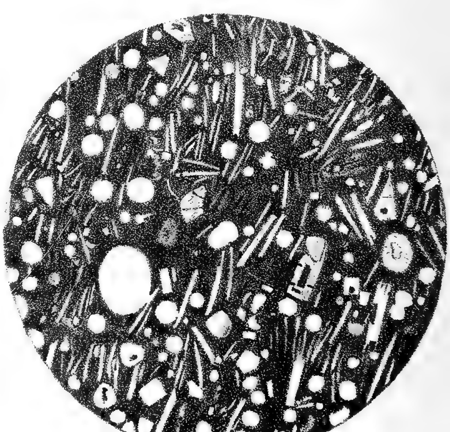
3 × 12



4 × 20



5 × 20



6 × 20

E. Drake del. et lith.

West, Newman imp.

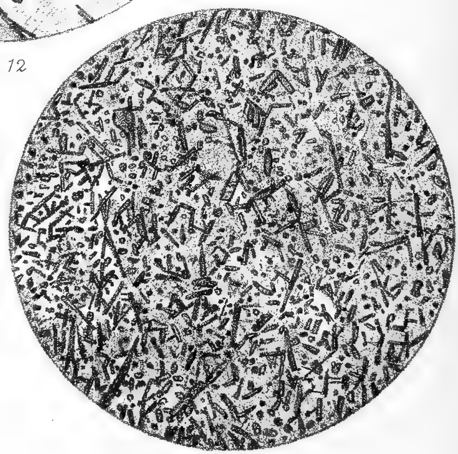
ROCKS FROM BRITISH EAST AFRICA.

1 × 12

2 × 12

3 × 12

4 × 12



5 × 12

E. Drake del. et lith.

West, Newman imp.

ROCKS FROM BRITISH EAST AFRICA.

11. CONTRIBUTIONS *to the* GEOLOGY *of* BRITISH EAST AFRICA.—PART III. THE NEPHELINE-SYENITE *and* CAMPTONITIC DYKES INTRUSIVE *in the* COAST SERIES. By Prof. J. W. GREGORY, D.Sc., F.G.S. (Read January 24th, 1900.)

[PLATE XII, *pars.*]

CONTENTS.

I. INTRODUCTION.

THE interest of the great volcanic series of British East Africa is lessened by one drawback. The sequence of the lavas evidently extended over a prolonged period; a vast interval must have intervened between the eruptions that poured out the materials which form the rolling plains of Laikipia and the Athi, and those that built up the existing craters of Longonot and the Kyulu Chain. But this long series of volcanic rocks is not associated with contemporary sedimentary deposits whereof the age is known. The lacustrine beds interstratified with the volcanic rocks will no doubt some day yield up the vertebrate fossils which probably occur in them. Until then, however, the evidence for the correlation of the volcanic series of British East Africa remains deplorably scanty.

Accordingly I was much interested when, as I was passing through Mombasa in 1893, Mr. C. W. Hobley told me of some dykes intrusive in Jurassic rocks at the back of Wasin, an island south of Mombasa, where the British East Africa Company then had a station. Mr. Hobley showed me a specimen of the rock forming Mount Jombo, which he regarded, no doubt correctly, as the massif whence the dykes were given off. As I was unable myself to visit the locality, Mr. Hobley most kindly procured for me specimens of the dykes, and gave me three specimens of the rock from Mount Jombo itself. This material forms the basis of the present paper.

Mr. Hobley [1] has himself referred to the occurrence of these rocks and marked the exact locality of one of the dykes on a map accompanying a paper published in 1895.

II. THE NEPHELINE-SYENITE OF MOUNT JOMBO.

Mount Jombo or Jomvu is situated in long. 39° 13′ east and in lat. 4° 26′ south [2] in the country of the Wadigo, in the south-eastern

[1] 'Upon a Visit to Tsavo & the Taita Highlands' Geogr. Journ. vol. v (1895) pp. 560–61 & map, p. 559.
[2] Admiralty Chart, No. 1390.

corner of British East Africa. It is about 18 miles west from the shore, about 16 miles north of Wanga, and 37 miles south-west of Mombasa. According to the Anglo-German boundary-survey it is 1519 feet high.[1]

The mountain is a massif of nepheline-syenite. The rock is coarse-grained, holocrystalline and hypidiomorphic. In hand-specimens the minerals recognizable are the large felspars, which often appear twinned on the Carlsbad type, and the nepheline, which is brownish, or grey tinged with 'light red'; it occurs in prisms 22 mm. long and 10 mm. in diameter. The pyroxene is dark, almost black, and occurs scattered through the rock in radial nests of needles, and sometimes in lines bordering the nepheline.

Examined microscopically the nepheline is seen to be usually allotriomorphic, though many idiomorphic crystals occur. The felspar is determinable as anorthoclase. The pyroxene is recognizable as ægyrine, the groups of which often include large corroded crystals of sphene. The specific gravity is 2·58. (See Pl. XII, fig. 3.)

Among the nepheline-syenites the Jombo rock resembles most closely that of the Sierra da Tingua in Brazil, but the nepheline is more often idiomorphic.

Owing to the distance of Mount Jombo from the coast-line, it probably occurs in the belt of the Duruma Sandstones; unless, which is of course possible, the fossiliferous Jurassic shales run westward up the low valley of the Umba River.

III. The Camptonitic Dykes.

The Jombo nepheline-syenite is associated with a series of dykes which traverse the surrounding sedimentary rocks. These dykes, whereof Mr. Hobley has given me three specimens, belong to the camptonitic group. The rock is grey, and studded with numerous acicular crystals of hornblende; while scattered through it are dark segregation-patches mainly composed of the same mineral.

Microscopic examination of the specimens obtained by Mr. Hobley shows that they agree closely enough to have come from the same dyke. The specimens differ mainly in coarseness of grain.

The phenocrysts are small but numerous, and consist of plagioclase, hornblende, and augite. The most conspicuous are the small needle-shaped hornblendes, which are idiomorphic; the species is the brown basaltic hornblende, having extinctions which, measured from c, vary from 0° to 8°, and a pleochroism ranging from dark brown to golden yellow; many of the crystals are twinned.

The pyroxene also is idiomorphic; its colour is light green; its extinction, measured from c, is over 35°; the species is, therefore, no doubt augite. The plagioclase mostly occurs as small, long, and lath-shaped crystals, but a few large felspar-phenocrysts occur in the rock. Ilmenite is fairly common, and apparently has used up all the titanium, for the pyroxene does not show the pleochroic border of

[1] Map of the Anglo-German Boundary Survey in Equatorial East Africa, sheets 3 & 4, I. D., W. O., Nos. 1003 & 1004.

the titaniferous augites, so striking a feature of the closely-allied monchiquites from Fernando Noronha described by Mr. G. T. Prior.[1] The analcite of the groundmass is small in amount. (See Pl. XII, fig. 4.)

A slide cut from a second specimen exhibits a fine-grained segregation-nodule, while the groundmass of the rock is coarser in grain, and contains more recognizable crystals of analcite.[2] I could find no quite satisfactory case of symmetrical extinction in the plagioclase, but the best case gave extinctions of 11° and 9°, which makes it probable that the species is oligoclase. The specific gravity of this rock is 2·59. (See Pl. XII, fig. 5.)

This rock presents characters intermediate between felspathic camptonites and the olivineless variety of monchiquites, for which the late J. F. Williams proposed the name fourchites.[3] From the rocks of the typical locality they differ mainly in containing a fairly large amount of felspar; the minerals appear to be fresher, while the augites are seldom twinned, have no violet pleochroic borders, and are very much smaller.

IV. The Age of the Jombo Series and the Duruma Sandstones.

The main interest of this small igneous series is that it provides the means of fixing a maximum date for the eruption of the easternmost of the volcanic rocks of British East Africa. Unfortunately, however, there is some doubt as to the exact age of the rocks into which the camptonites are intrusive.

The general geology of the belt of coast-lands between the Uganda road west of Mombasa on the north, and the Anglo-German boundary west of Wanga on the south, has been briefly described by Mr. C. W. Hobley.[4] He shows that the country between the Archæan plateau and the sea consists of three belts of sedimentary rocks; along the shore are Pleistocene sands, raised coral-reefs, and limestones; behind these are some fossiliferous shales with Jurassic fossils; and to the west of this series is a belt of massive sandstones, which form the range of the Shimba Mountains. The volcanic rocks are intrusive into these massive sandstones, the age of which it is necessary to consider.

The Jurassic rocks of Eastern Equatorial Africa were first discovered by J. M. Hildebrandt[5] in 1876, near Mombasa, where he collected some fossils described by Beyrich.[6] The Jurassic rocks of

[1] 'Note on the Occurrence of Rocks allied to Monchiquite in the Island of Fernando Noronha' Min. Mag. vol. xi (1897) pp. 171–75.

[2] L. V. Pirsson, 'On the Monchiquite or Analcite Group of Igneous Rocks' Journ. Geol. vol. iv (1896) pp. 679–90.

[3] 'The Igneous Rocks of Arkansas' Ann. Rep. Geol. Surv. Arkans. 1890, vol. ii, p. 107.

[4] Geogr. Journ. vol. v (1895) pp. 560–61.

[5] 'Von Mombassa nach Kitui' Zeitschr. Gesellsch. Erdk. Berlin, vol. xiv (1879) p. 241.

[6] 'Ueber Hildebrandt's geologische Sammlungen von Mombassa' Monatsber. k. Preuss. Akad. Wissensch. Berlin (1878) pp. 767–75.

that district occur on the mainland opposite Mombasa, where they may be seen in the bed of the estuary west of Freretown, on the slopes of the three hills known as the Çoroa Mombasa, and opposite Mombasa on the main slope from Makupe Ferry up to Changamwe. The beds are a series of iron-stained shales, with lines of ironstone-nodules, the whole dipping eastward. Thence I collected a number of cephalopods which Mr. G. C. Crick, of the Natural History Museum, has kindly undertaken to describe. The fauna shows that the beds at this locality (as previously held by Futterer[1]), are mainly of Kimeridgian age, from the zone of *Aspidoceras acanthicum*.

South of this point fossiliferous Jurassic rocks reappear near Tanga, Saadani and Mtaru, where the fossils, as described by Futterer, Jækel, and Törnquist, show that the beds are of Middle Jurassic age, being Oxfordian and Callovian.

Immediately to the west of this belt of Upper and Middle Jurassic rocks is a great series of sandstones, which appear to reach their highest development in the Shimba Mountains. Baron Stromer von Reichenbach has proposed for them the convenient name of Duruma Sandstones. Hildebrandt clearly regarded these beds as older than the Jurassic, for they are described in Beyrich's paper[2] as extending from the Jura-formation to the Archæan Series.

But this view has not been always accepted. In an account of the geology of Usambara, the country immediately south of the Anglo-German boundary, and of the district west of Bagamoyo, in both of which the geological sequence is similar to that near Mombasa, Joseph Thomson claimed the whole series between the Archæan and the Pleistocene (which I presume covers his Tertiary) as Carboniferous. This conclusion was apparently based on his own identification of some fossils which he thus describes[3]:—'The contained fossils, such as corals and marine shells, were, as far as seen, in too imperfect a state of preservation to be recognizable, and my short search did not enable me to secure any specimens capable of determination, although I have no doubt that a more careful examination will bring to light many good fossils.' A subsequent reference to these fossils in 1881 is more important, as he then mentions an exact locality[4]:—'At Umba, in Usambara, I found one bed of limestone with numerous fossils of characteristic Carboniferous types.'

Baron Stromer von Reichenbach[5] has already thrown doubt on this identification, and I am not aware that any fossils from Umba have been definitely determined. The Rev. J. P. Farler[6] has briefly described the lithological character of the rocks near Umba, and

[1] 'Beiträge zur Kenntniss des Jura in Ost-Afrika' Zeitschr. Deutsch. Geol. Gesellsch. vol. xlvi (1894) pp. 2–15 & 49.

[2] Monatsber. k. Preuss. Akad. Wissensch. Berlin (1878) p. 774.

[3] 'Notes on the Geology of Usambara' Proc. Roy. Geogr. Soc. n. s. vol. i (1879) p. 560.

[4] 'To the African Lakes and Back' vol. ii (1881) p. 301.

[5] 'Geologie d. deutschen Schutzgebiete in Afrika' Munich, 1896, p. 24.

[6] 'The Usambara Conntry in East Africa' Proc. Roy. Geogr. Soc. n. s. vol. i (1879) p. 87.

they would answer for the common East African Jurassic type; and Stuhlmann,[1] in his geological map, marks Umba as Jurassic.

Thomson's identification however, appears to rest in part on lithological resemblances. He remarks that lithologically the sandstones agree with those described by Thornton at Mombasa; but, as the only sandstones on Mombasa Island are Pleistocene, any lithological resemblance to them is not a proof of Carboniferous age. Thomson also compares the Usambara limestones to those of Mombasa; but this does not strengthen his case. For, though I examined many of the coast-sections of Mombasa Island, and also traversed the island in several directions, I saw nothing but Pleistocene deposits, such as alluvium, raised reefs, and red sandstones. Some of the limestones, however, are so full of Archæan débris and garnets that they appear very ancient. One of these limestones from near the Administrator's house at Kilindini is full of garnets, orthoclase, microcline, plagioclase, quartz, tourmaline,[2] etc., and its aspect in hand-specimens resembles that of a calciphyre. This apparently ancient limestone may well be the rock that Thomson had in mind when correlating the Mombasa with the Usambara limestones. But the former are certainly late Kainozoic, and their age may be merely a matter of a few centuries.

A further blow at the Carboniferous age of the coast series has been given by the discovery of an ammonite at Kessa, west of Bagamoyo. This ammonite, though badly preserved, has been determined by Futterer[3] as a member of the group of *Perisphinctes Martinsi*. I am not sure of the exact position of this locality, which is simply described by Futterer as west of Bagamoyo. The most probable name marked on the Langhans' Deutscher Kolonial-Atlas (1897, map No. 22) is Kwa Kiuisa, which is almost due west of Bagamoyo on the meridian of 38°; and Thomson, in his map at the end of vol. ii. of 'To the African Lakes and Back' marks his belt of limestone only about 5 miles west of the 38th meridian, and at the western end of the sedimentary series. The ammonite occurred in a micaceous quartziferous limestone, which rests conformably on the sandstones of Usaramo, these being in all probability a continuation of those of Duruma. And Futterer concludes, 'it appears very probable that the Usaramo Sandstones also are Jurassic, and their supposed older date cannot be maintained for at least the greater part of them' (*loc. cit.*).

The same conclusion is maintained by Stromer von Reichenbach,[4] who points out that 'it is still very problematical whether all these rocks are of the same age, and whether they belong to the Carboniferous. The similarity of their stratification and of their petrographical characters with the Jurassic beds, and especially

[1] 'Mit Emin Pascha ins Herz von Afrika' Berlin, 1894: geol. inset-map on large map.

[2] The occurrence of some of these minerals in the existing shore-sands of Mombasa has been recorded by Mr. Walcot Gibson in his 'Geological Sketch of Central East Africa' Rep. Brit. Assoc. 1893 (Nottingham) p. 758.

[3] Zeitschr. Deutsch. Geol. Gesellsch. vol. xlvi (1894) p. 49.

[4] 'Geologie d. deutschen Schutzgebiete in Afrika' 1896, p. 28.

the already-mentioned discovery of an ammonite in the limestone of Kessa, indicate a much less remote age for at least a part of the sandstone-formation.' With the evidence at present available it is clear that we cannot go far beyond that author's cautious conclusion. It is certain that approximately parallel to the coast-line runs a belt of Middle and Upper Jurassic shales, resting upon a series of shales and sandstones, which are said to be conformable to them. In one place the Jurassic rocks are proved to extend across almost the whole sedimentary belt; but it is possible that the lower beds of this belt may be pre-Jurassic, though the evidence on which they were claimed as Carboniferous is valueless. It is, therefore, probable that Thomson's marine 'Carboniferous' shells are Jurassic, while his corals are probably specimens of weathered recent coral-limestones.

If any part of the series is pre-Jurassic, then we might expect to find in it some representatives of the Cape Series, which have been recorded as far north as Nyasa, and then, after a great break, in the Sabaki River by the 'Second Stockade' (lat. 3° 3′ south, long. 39° 5′ east), that is, about 100 miles west-north-west of Mombasa. I there collected a considerable number of specimens of a mollusc which has been determined by Prof. Amalizky as *Palæanodonta Fischeri* (Amal.). These Sabaki Shales are therefore Upper Carboniferous.[1]

The sedimentary series on the coast-lands of British East Africa and Usambara may, then, be provisionally arranged as follows, in descending order :—

1. Pleistocene reefs, limestones, alluvium, and laterites.
2. Jurassic shales and sandstones: Kimeridgian, Oxfordian, and Callovian.
3. Possibly a pre-Jurassic part of the Duruma Sandstones.
4. Magarini Sandstones: ? Triassic.
5. Sabaki Shales: Upper Carboniferous.

The attention of travellers in East Africa may be called to the desirability of endeavouring to collect specimens of the fossil terrestrial plants which various travellers have seen in the Duruma Sandstones, in order to determine the exact age of that series; and in the second place to observe into precisely which member of this sequence the camptonite-dykes are intrusive.

In the Sabaki Valley the great flow of lava that forms the Yatta plateau is no doubt younger than the Sabaki Shales; but, so far as I know, the only case of actual contact of the post-Archæan igneous rocks of British East Africa with the sedimentary series is afforded by the nepheline-syenite of Jombo and its camptonite-dykes. And though the evidence is not conclusive, it is probable that these rocks are not older than the early Mesozoic, and may be Jurassic or post-Jurassic.

Further evidence of the Jurassic age of the Duruma Sandstones is given by a coral collected by Mr. Hobley west of Buni Hill (lat. 3° 58′ south, long. 39° 35′ east), a few miles west of the ammonite-

[1] See my work on 'The Great Rift Valley,' 1896, p. 229.

bearing shales. The coral occurred in a compact grey limestone. The exposed parts of the fossil are marked by patches of white calcite breaking in cleavage-rhombs, but one section shows enough of the septa for the genus to be provisionally determined.

The corallites are cylindrical in section, and the largest is about 10 mm. in diameter; they are laterally free, but, judging from their position in the specimen, they appear to be part of a cæspitose coral. The wall is thin, and the costæ are prominent. The septa are about 48 in number: that is, there are five complete orders. The members of the first three orders are long, thin, and subequal; those of the 4th and 5th orders are shorter and also subequal. There is a large trabecular columella. There is no sign of a fossula or of pali, or of tetrameral symmetry. The affinities of the coral are accordingly with *Aplophyllia*; it will be noted, however, that there is no conclusive proof from this small specimen of a cæspitose habit. It is conceivable that the corallites, instead of being part of an arborescent colony, may be simple and only accidentally associated; yet this is improbable.

The specimen may be provisionally determined as an *Aplophyllia* (syn. *Rhabdophyllia*), and compared with *A. cervina*, Etienne, from the Oxfordian of Switzerland.[1]

EXPLANATION OF PLATE XII (*pars*).

Microscopic sections of igneous rocks from Mount Jombo.

Fig. 3. Nepheline-syenite (No. G. 925, p. 224). The dark patch consists of ægyrine, with included crystals of sphene: below is a large Carlsbad twin of felspar, and on the right a large plate of nepheline. × 12.

4. Camptonitic dyke-rock (No. G. 923, pp. 224–25). The dark phenocrysts are partly basaltic hornblende (as, for instance, the two large crystals at the top on the left) and partly pale green augite (as, for example, the large crystal in the centre and that at the top on the right). A few small diamond-shaped crystals are sphene. The colourless phenocrysts are felspar. At the top, both on the right and on the left, are patches of analcite. × 12.

5. Segregation-patch in camptonitic dyke-rock (No. G. 921, p. 225). The section shows needles of deep-brown basaltic hornblende and pale green augite, with a little sphene, in a base consisting mainly of analcite.

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[1] Koby, 'Monogr. Polyp. jur. Suisse' Mém. Soc. Pal. Suisse, vol. xi (1884) p. 191 & pl. lvi, figs. 3–7.

12. Bala Lake *and the* River-System *of* North Wales.

By Philip Lake, Esq., M.A., F.G.S. (Read February 7th, 1900.)

[Abstract.]

In this paper the Author begins by showing that topographically Bala Lake belongs to the same valley as the River Wnion—the valley of the Bala Fault; and he believes that the whole drainage of the valley originally flowed south-westward, and entered the sea near Barmouth.

He then examines the possible outlets, and shows that the lake is probably rock-bound in all directions except towards the south-west, where there is no conclusive evidence.

He describes the faults which occur near the watershed that separates the Wnion from the streams flowing into Bala Lake, pointing out that they are closely related to the form of the valley, and that the watershed coincides with a transverse line of fault. From this he infers that the formation of the lake is possibly due to earth-movements.

The watersheds of several other similar valleys are examined, and are shown to lie in one straight line; whence it is concluded that they must have been produced by some general cause, probably a slight differential movement.

The general drainage-system of North Wales is next discussed. Attention is drawn to the existence of a series of long and nearly parallel valleys running from north-east to south-west, which divide the region more or less completely into a number of strips. The drainage of each strip is now independent, and flows in most cases into the long valley lying south of it. But from the fact that the chief streams in each strip have their representatives (flowing in the same line) in the adjacent strips, it is concluded that before the formation of the long valleys the streams were continuous.

The centre from which these streams radiate lies in the high ground near the sources of the Conway; and the Author believes that this was the centre of an original radial system of drainage, and that this radial system was subsequently broken up into sections, by the formation of the long valleys which now run from north-east to south-west—each of these long valleys carrying away the drainage of one of the sections. He attributes the formation of the long valleys to faulting.

Discussion.

Mr. Hopkinson said that he came to hear this paper expecting that it would have a direct bearing on the question of obtaining a supplementary supply of water for London from Bala Lake. Although he was disappointed in that, he had listened to the Author's admirable exposition with the greatest interest, perhaps

more so than if this practical question had been discussed by him. The paper had, however, some bearing upon this subject. Although the drainage-area is large, the rainfall heavy, and the rocks are comparatively impervious, he had thought that there might be a difficulty in raising the level of the water in the lake sufficiently to afford the necessary legal compensation to the riparian rights below it, because of the various possible outlets at a little higher level than the existing one, the presence of which outlets the Author had pointed out. The submergence of the town of Bala would perhaps be a small matter, compared with the importance of the supply of such pure water to London. There was one point which he should like to see made clearer. He had visited Bala Lake in all states of the weather, and he had noticed that a considerable area of land at the northern end of the lake was soon under water when the rainfall was heavy, from which he inferred that the margin of the lake had there a gentler slope than the Author's words would lead one to surmise.

Mr. Strahan observed that this paper dealt with two highly speculative subjects. He understood the Author to state that the lake was rock-bound in all directions except to the south-west, where it was possibly dammed by Drift. If this Drift-dam were due to earth-movements, those movements must be of post-Glacial age. But movements of so late a date and on such a scale were unknown in this country. The alluvial flat at the foot of the lake which the Author had ascribed to the Dee was more probably the alluvial fan of the Treweryn, a turbulent tributary scarcely less important than the Dee itself. The Author had shown that there was an intimate connexion between the faulting and the form of the valley, but this might be attributed to the fact that the faults threw in soft strata among hard volcanic rocks; the Bala Fault was believed to be of pre-Triassic age, and it was hardly likely that any alteration of surface-level produced by it could have survived from so early a period. The contention that portions of certain north-and-south stream-courses formed relics of once continuous radiating valleys was too great a demand upon his credulity.

Though not accepting all the Author's conclusions, he congratulated him upon a highly suggestive communication.

Prof. Groom thought that the Author had made out a very strong case for the original connexion between the different river-sections radiating from the North Wales centre. With respect to the dislocations, both the Author and himself had often been struck with the close connexion which existed between faults and valleys in North Wales. The dominant movements along the north-east and south-west lines appear to have occurred at a number of distinct epochs in North Wales and the Border counties. Continental geologists had almost invariably regarded the old Welsh Highlands as a part of the Caledonian system, but there appeared to be little doubt that the chief folding had taken place in Old Red Sandstone times, as Ramsay had long ago maintained. Other movements in the same sense had taken place towards the close of the Upper

Palæozoic period, and later movements some time after the deposition of the Lower Mesozoic formations. A lake-system was regarded by many geologists as indicating a 'youthful' drainage, and it would be interesting to know whether any of the dislocations of Bala Lake had affected the Pleistocene deposits.

Mr. SALTER said that he was much interested in the latter portion of the paper, in which a most instructive and complicated system of river-capture was described. He asked the Author whether he had come across any corroborative evidence, other than the surface-feature noted, such as beds of gravel or other fluviatile accumulations at high levels. The view that considerable earth-movements had probably taken place in recent geological times seemed to the speaker to be quite feasible, and might explain the great height of a very interesting deposit near by, at Moel Tryfaen.

Mr. LAMPLUGH asked the Author in what manner he supposed the transverse faults to have taken effect in intercepting and diverting the original radial drainage.

The AUTHOR, in reply, regretted that he had not been sufficiently explicit with regard to the formation of Bala Lake. Although he believed that the waters of the valley in which that lake now lies originally flowed in a south-westerly direction, and although it was impossible, without a boring, to prove that the lake is rock-bound in this direction, yet for reasons stated in the paper he thought that the lake now lies in a rock-basin, the basin having been completed by earth-movements which closed it in on the south-west. He admitted the difficulty of distinguishing between the direct effects produced by faults, and the secondary effects due to difference in hardness of the rocks brought into contact with one another; but he would point out that the oblique faults which seem to have produced the convex bend in the valley have rocks of similar character on both sides.

The paper was confessedly speculative, but he could not believe that the coincidence in direction of the numerous streams referred to the original radial system was merely accidental. He was unable to offer any opinion as to the age of the radial system, or of the system of valleys which run from north-east to south-west.

As to the manner in which the radial system was broken up, he was inclined to believe that movement took place along pre-existing faults which run from north-east to south-west. The ground on the south-east side of each fault was raised across the course of the radial rivers, and in most cases so rapidly that these rivers were unable to keep to their original direction and were deflected along the lines of the faults.

13. *On the* GEOLOGY *of* NORTHERN ANGLESEY: PART II. By CHARLES A. MATLEY, Esq., B.Sc., F.G.S. (Read January 10th, 1900.)

[PLATES XIII & XIV—Map & Sections.]

CONTENTS.

IN a recent communication [1] I discussed the stratigraphical relationships of the rocks of Northern Anglesey, and showed that the region had been profoundly affected by earth-movements. Having now completed the mapping of that part of the district which I called the 'Northern Complex,' that is to say the area between Cemaes and Bull Bay, I venture to bring the results before the Society, with map and sections. It has been ascertained that some of the dykes of Northern Anglesey are composite in character, and a short account of these and of the other intrusive rocks is also given.

I. STRATIGRAPHY OF THE NORTHERN COMPLEX.

In my previous paper the Northern Complex was stated to contain rocks of undoubted Ordovician age, rocks of the Green Series, and a third group characterized by limestones and quartzites. The last-mentioned group will be here referred to as the Llanbadrig Series, from its development in the neighbourhood of Llanbadrig Church. The succession, in descending order, is as follows:—

C. The Llandeilo Rocks—conglomerates, grits, sandy and argillaceous shales and slates, and ironstone.
B. The Llanbadrig Series—quartzites, limestones, slates, gritty slates with bands of grit, and pebbly slates.
A. The Green Series—represented in the 'Northern Complex' mainly by greenish and bluish slates.

The rocks strike in an east-south-easterly direction, and the dip, almost always northerly, is usually high. A well-marked transverse fault runs south-westward from Hell's Mouth, dividing the Complex into western and eastern portions.

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 635–75.

(*a*) The Llandeilo Strata.

A glance at the map (Pl. XIII) will show that these rocks occupy four strips of ground in the western part and three in the eastern part of the area. These latter three and the northernmost one of the former lie on the same line of strike. The full succession does not occur in any one of these outcrops, but can be demonstrated by piecing together the sections seen in several localities: it is as follows:—

	Probable thickness.	Fossils.
Cd. Black argillaceous shales	40 feet (top not seen)	See (α) & (β) Quart. Journ. Geol. Soc. vol. lv (1899) p. 639.
Cc. Ironstone, in part oolitic......	20 feet	See (γ) *ibid.* p. 640.
Cb. Grey quartzose shales or slates striped by thin black laminæ.	150 feet	Crinoid-stems.
Ca 2. Pale conglomerates and grits.	500 feet	See (δ) to (η) p. 640 of the above-quoted paper.
Ca 1. Red-purple conglomerate.	180 feet	———

(1) Between Hell's Mouth and Porth Wen Bay.—The basal beds are best exposed here. The lowest bed is a great purple conglomerate which dips north-north-eastward at 65° to 70°, but the outcrop is very variable in width. Its relation to the underlying rock will be described in discussing the quartzites of the Llanbadrig Series (p. 244). The matrix is very sandy, reddish purple in colour, and the included pebbles, of all sizes up to more than 2 feet in length, are quartzite and quartzose grit, mainly reddish, some white.

Pebbly grits, interbedded with finer slaty beds and containing some bands of conglomerate, succeed the purple conglomerate to the north. The junction may be natural near Hell's Mouth, but it is a fault between Craig Wen and Porth Wen Bay. These beds are usually pale, or even white, sometimes of a sage-green tint. About 12 feet of soft blue-black shale is seen at Porth Wen Works: this, however, may be faulted in.

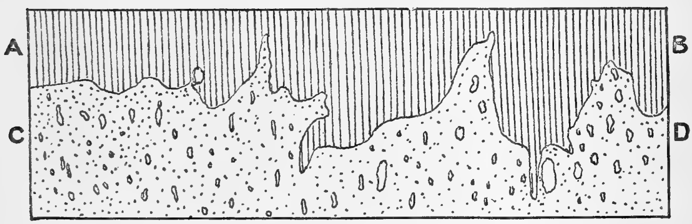
The series is repeated in the headland of Torllwyn. The purple conglomerate, with part of its thickness cut out, forms a band from Porth Adfan to Porth Wen Bay. It has been brought up and thrust over the grits, and in Porth Adfan a few feet of a still higher zone, namely the banded sandy shales, cleaved, crushed, and full of small thrusts, appear below the thrust. The pale gritty and pebbly beds follow, and continue to the northern extremity of the headland, where their dip is about 50° north-north-eastward.

All these beds have been strongly compressed by movement from the north, the effect of compression being especially marked in the case of the pebbles of the purple conglomerate. The principal cleavage agrees in amount with the dip of the conglomerate, but the

rock is full of small inosculating shear-planes hading northward at a smaller angle with the horizon than the dip of the principal cleavage. Along these shear-planes the matrix is discoloured and dragged out, while the pebbles have been stretched into phacoids and their extremities tailed out. An example obtained from the conglomerate north of Porth Wen Works, where these effects are beautifully displayed, shows one of these pebbles which has attained its present shape by differential yielding along several parallel planes of shear, in spite of which it has remained unbroken.

While the stratigraphy brings out the general west-north-westerly strike of the beds, the cleavage-strike is conspicuously east and west. Locally, as in fig. 1, these strikes are quite transverse to each other. The obliquity of the cleavage to the strike of the folds and faults shows that the former must be of later date than the latter. Its effect is to obscure the structure of the strata, and sometimes to produce even an appearance of unconformity between two perfectly conformable beds. (See fig. 1, from the coast north of Porth Wen Works.)

Fig. 1.—*Part of an horizontal ledge of rock on the coast, on the western side of Porth Wen Bay, about 90 yards north of the northern Purple Conglomerate.*



A B = Gritty slate, the fine lines showing cleavage.
C D = Pebbly grit.

[Length from A to B = $2\frac{1}{2}$ feet.]

The above section illustrates the junction of two conformable beds, the appearance of unconformity being due to distortion by pressure.

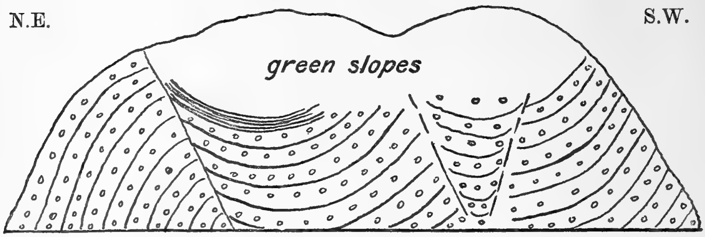
From the width of its outcrop near Hell's Mouth the thickness of the purple conglomerate is estimated at 180 feet. The overlying beds are more difficult of measurement, owing to cleavage and to the probable occurrence of undetected faults, but a thickness of 500 feet is suggested.

(2) Llanlliana Head.—The purple conglomerate, as before, lies here upon a massive white quartzite, and dips steeply northward. The pale conglomerates and grits follow, faulted against the purple rock, and they are overlain by black-banded, grey, quartzose shales, which are changed locally into a blue quartzite, and contain above Porth Llanlliana casts of crinoid-stems.

These rocks are arranged in a faulted syncline, north of which the

beds resume their north-easterly dip. A sketch of the headland, taken from near the Middle Mouse (Ynys Badrig), is reproduced in fig. 2.

Fig. 2.—*Llanlliana Head, sketched from near Ynys Badrig.*



[Scale: 20 inches = 1 mile.]

The beds are cleaved obliquely to the bedding-strike, and in one faulted portion of the banded beds above Porth Llanlliana I observed the cleavage-strike to be at right-angles to the strike of the bedding.

(3) West of Porth Llanlliana.—The basal conglomerates and grits and the banded beds come in here between converging faults. As at Llanlliana Head the general structure is a syncline followed to the north by an anticline; but the rocks are much broken by faults (some of which are thrusts), and the detailed structure is seen to vary considerably as we pass from west to east. All the beds are cleaved at high angles. Some of the bands of conglomerate are very coarse.

On the coast the conglomerate is faulted against the quartzite, inland it lies directly upon it, but the purple conglomerate which was so conspicuous a feature of the basal beds to the east is here represented by a pale conglomerate. A few purple bands may be seen, however, on the coast (see fig. 13 of my previous paper, vol. lv of this Journal, p. 673), close to which I have found an assemblage of fossils similar to those recorded from Ogof Gynfor.

(4) Ogof Gynfor.—Some account of the rocks here, with a figure of the coast-section and a list of fossils, was given in my previous paper (*op. cit.* pp. 640, 648). Its structure consists of two broken synclines, between which appears a shattered anticline of quartzite. The northern syncline is cut out to the east by the overthrust of calcareous beds of the Llanbadrig Series. Faulted in between the quartzite and the overthrust is the Penterfyn ironstone, the details of the section exposing the latter being as follows:—

		Feet.
Cc.	Ironstone in flaggy beds, with shaly partings which contain Glenkiln graptolites. (Top not seen.)	17
	Black shale	2
Cb.	Blue sandy shale	2

(Base not seen, but soon faulted against quartzite.)

The broken syncline on the south side of the quartzite-ridge is interrupted by a cross-ridge of quartzite. Conglomerate and black shale occur near Is-allt.

(5) Porth Padrig. The black argillaceous shales, with Glenkiln graptolites, of Porth Padrig have a little oolitic ironstone at their base. The outcrop is bounded north and south by faults.

(6) Porth Pridd. (See Pl. XIV, Section 3.) The exposures here fix the horizon of the Penterfyn and Porth Padrig beds. South of the Porth, and faulted against the Llanbadrig Series, may be seen a few feet of a conglomeratic grit, which resembles the fossiliferous beds of Ogof Gynfor. This is succeeded, first by about 150 feet of the black-banded grey beds, and then by a black oolitic ironstone identical in character with that seen at Penterfyn and Porth Padrig. The ironstone passes up into 40 feet of soft black argillaceous shale, similar to that which occupies a corresponding position at Porth Padrig.

All these beds dip at 65° in a direction a little east of north, and the sequence so far is regular, but from this point northward complications ensue. First the banded grey beds, now shattered to a breccia, are repeated by a thrust which brings them against the soft black shale. More soft black shales follow, and then the banded beds, the ironstone, and the argillaceous shales are again repeated, with small complications due to faulting and thrusting. Finally, the succession is terminated by an overthrust of the Llanbadrig Series, the steeply-inclined thrust-plane being broken, however, *en échelon* by small cross-faults.

(7) East of Porth Pridd.—This is a narrow strip of the basal conglomerates and grits. They are cleaved, and for the most part pale, but patches of purple appear in places. Hence the reddish-purple colour of the basement-beds (as seen between Porth Llanlliana and Porth Wen) may be inferred to constitute merely a local feature, and to die out with marked rapidity, indeed almost with abruptness, both west and east of the typical area. The northern boundary is an overthrust of the Green Series; the southern boundary is also faulted along most of its course, but in one place the pebbly grits lie upon white quartzite. I found one specimen of *Orthis calligramma* var. *Carausii* in these beds.

These areas of Llandeilo rock, insignificant as they are in extent, are of some importance from a tectonic point of view, as they reveal the existence of at least four shattered synclines between anticlinal areas of older rocks. They are not, however, simple synclines, but are themselves usually folded and always faulted. Hundreds of feet of the basal beds are proved to be sometimes absent from the latter cause. The northern boundaries of some, and possibly of all these complex synclines are overthrusts, consequently the Northern Complex is not merely a folded, but an overfolded area.

The close correspondence of the sequence here with that of the Ordovician area south of the Green Series has been previously noticed. Prof. Hughes's description of the latter area[1] makes this point sufficiently clear.

(*b*) The Llanbadrig Series.

The rocks of this group come in above the Green Series, and below the Llandeilo Beds. Apart from its characteristic limestones the series is a distinctly gritty one; the shales contain abundant quartz-grains,[2] are interbedded with bands of quartzose grit or quartzite, and pass up into conglomerate. The prevailing colour may be stated as a dull olive-brown, relieved by horizons of grey, green, sage-green, or even black among the shales, of blue or pale grey in the limestones, or of white in the massive quartzites. The succession, which has not been fully made out, may be best studied in the coast-sections.

(i) Area west of the Hell's Mouth Fault.—Commencing at the western end of the Complex, several masses of the Llanbadrig limestones may be seen involved in the crush-zone of Wylfa Head, but most of the quartzite-masses here seem to be altered fine grits of the Green Series.

On the eastern side of Porth y Wylfa, a narrow wedge of shattered quartzite, with an included bed of impure limestone, is caught up in the Green Series between thrust-planes, which hade as usual to the north.

At Penrhyn occurs the overthrust area figured in my previous paper (*op. cit.* pp. 660, 662). The broken grits and slates which form the 'crush-conglomerate' here do not possess the distinctive green coloration of the flaggy slates to the south, and on the eastern side of Trwyn y Penrhyn the junction of the two groups is rather abrupt and apparently faulted, though wedges of typical green slates appear north of the break. The western boundary is more arbitrarily drawn, and there may be a passage between these rocks and the crush-conglomerates of the Green Series along the coast to the west.

We pass now to the coast-section (Pl. XIV, Section 1) at Pig y Barcud and along the eastern shores of Cemaes Bay. The limestone at Pig y Barcud is shaly, with black anthracitic partings, much contorted, and intersected by numerous small thrusts. This and two more limestone-masses to the west are isolated portions of the Trwyn y Parc Limestone and occupy an overfolded syncline. They are overridden by broken slaty and gritty beds (with some bands of quartzite) of the same character and on the same horizon as the crush-conglomerate at Penrhyn. We may call them Trwyn y Parc Slates and Grits. In them occurs a crushed dyke, and

[1] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 16.

[2] The quartz-grains of some of the gritty shales, grits, and quartzites are seen under the microscope to be remarkably rounded. A grit from the broken-up beds of the Green Series at Porth y Wylfa showed similar well-rounded grains.

they are followed by the Trwyn y Parc Limestone. In much of this limestone the bedding cannot be made out, in parts it is a recemented breccia. The section shows that the limestone is underlain by the authiclastic rocks of Trwyn y Parc. Though the change from grits and slates to limestone is abrupt, and the junction in places is certainly one of movement, the conclusion is inevitable that the Trwyn y Parc Limestone succeeds the Trwyn y Parc Grits and Slates. A passage between the two can be seen along the course of the rifle-range in Cemaes Bay.

The parallel sections (see Pl. XIV, fig. 1) show how greatly the details vary at short intervals along the line of strike.

On reaching the southern cove of Porth Padrig a marked change is observed in the rocks, introduced apparently by a fault. Pale quartzites and quartzose grits are now the characteristic feature, interbedded with gritty shales, some with broken-up grit-bands. The quartzites are either flaggy and well-bedded with shaly partings, or massive and obscurely bedded, though exhibiting clastic grains. The gritty beds vary in colour, being light grey, greenish-grey, blue-grey, sage-green, and yellowish, and some of them are crushed to fine 'augen'-grits. In this group also occurs a rotten ferruginous rock, which has been worked for umber. There is moreover some limestone, one mass lying between tide-marks, and another mass appearing in the cliff. This latter overlies a 'crush-conglomerate,' from which it is separated by an anticlinal curve, as shown in the section (Pl. XIV, fig. 1).

The faulted patch of Llandeilo Shales mentioned on p. 237 now intervenes, beyond which reappear the quartzites with their associated shaly rocks. They form the northern part of Porth Padrig, where they were once worked for 'china-stone.'

The rocks of Porth Padrig are so much broken that their structure and relationships cannot be made out with any certainty, but they appear to be part of a shattered synclinal fold, the core of which is represented by the graptolitic shales. Thus they may be provisionally considered to belong to a higher horizon than the Trwyn y Parc Limestone. Beds of much the same character occur in the south of Porth Wen Bay, where they similarly appear to belong to a higher zone than the limestone formerly quarried there.

Section 2.—This section (Pl. XIV) is drawn in a north-easterly direction through the broken rocks at Llanbadrig, and is practically a continuation to the north-east of Section 1. The quartzite at Llanbadrig Point has been previously described.[1] The succeeding beds are mostly crushed shales and slates, so shattered that the contorted character of the whole is much obscured, though occasionally revealed. They include some broken-up bands of grit and quartzite, and are more shaly than the rocks at Trwyn y Parc; but, like the latter, they pass up into a limestone, which towards Llanbadrig Church contains black shale of a character similar to that occurring in the limestone of Trwyn y Parc Quarry. The coast-

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 653.

section shows the fractured condition of these rocks so well that further description is unnecessary.

Near Llanbadrig Church the shaly beds give place to similar rocks, with rather thick irregular bands and lenticles of quartzite and quartzose grit. As they are followed towards Ogof Gynfor they are observed to include some limestone, and to pass up into pebbly slates. These beds are much crushed, and are succeeded by the faulted-in Llandeilo rocks of Ogof Gynfor.

North-east of Ogof Gynfor.—The thrusting of the Llanbadrig Series over the Ogof Gynfor Llandeilo strata brings up a long strip of impure limestone that is traceable inland to Llanlliana Farm. The lower beds of this zone are calcareous slates or shales, thinly laminated, but frequently welded into a limestone, and they pass up into massive limestone. The apparent dip is steeply to the north. Thrusts occur in these beds, bands of grey limestone terminate in a tongue-like manner, and the whole is much jointed, veined, and irregular. Some of the limestone splits into large phacoids by the development of curved joints. These calcareous beds are limited to the north-east by a nearly vertical fault.

Gritty slates with pebbly and conglomeratic zones succeed, which are identical with the rocks between Llanbadrig Church and Ogof Gynfor. Here they pass up into a quartzite which is the highest recognizable zone of the Llanbadrig Series, so that they must lie above the calcareous beds just described. Consequently the junction is a normal fault, but it has been evidently subjected to crush, as small thrusts at a low angle have driven the pebbly slates for a short distance over the dark calcareous shale and limestone. The coast-exposures show that this pebbly group contains two or three thin lenticular zones of limestone which have been broken by gently-sloping thrust-planes and the dislocated portions carried 1 to 3 feet southward. A more important thrust, hading at 35° from the horizontal, may be followed from the base to the summit of the cliff near by. Inland, towards Llanlliana Farm, these beds are finer, with tiny quartz-pebbles and flaggy bands of quartzose grit.

A white quartzite succeeds these pebbly beds. On the coast it is cut out before reaching the base of the cliff, by a fault which lets down the Llandeilo rocks. Inland it is about 100 feet thick, and the Llandeilo Beds rest upon it. This quartzite presents remarkable stratigraphical features, and its significance will be separately discussed (p. 244).

The upper portion of the Llanbadrig Series is repeated at Porth Llanlliana. Calcareous shales, contorted and cleaved, with some massive limestone, are succeeded by slaty beds, the upper part of them pebbly, which pass into the quartzite-zone of Llanlliana Head.

From the foregoing descriptions a general idea of the Llanbadrig succession may be gained; the lowest beds are the

Trwyn y Parc Grits and Slates, seen at Penrhyn, Trywn y Parc, and Llanbadrig; they are followed at Penrhyn, Trwyn y Parc, and Llanbadrig by the Trwyn y Parc Limestone,

The upper beds are, in ascending order:—

Slates with grit- and quartzite-bands (seen near Llanbadrig Church).

Pebbly slates (west of Ogof Gynfor; west of Porth Llanlliana; and southern slopes of Llanlliana Head).

Quartzite (Ogof Gynfor to Is-allt; west of Porth Llanlliana; and Llanlliana Head).

The calcareous zone west and south of Porth Llanlliana may be referred with some probability to the horizon of the Trwyn y Parc Limestone, but the quartzites and shales of Porth Padrig are of uncertain horizon. They perhaps come in between the upper and lower divisions of the series.

(ii) Area east of the Hell's Mouth Fault.—The slaty beds of the Green Series are found much farther north on the eastern than on the western side of the Hell's Mouth cross-fault. Limestone is seen to the north of the Amlwch Road, with an outcrop in shape resembling the quarter of an ellipse. Its presence among the Green Series is due to earth-movements, and the green slates near it are contorted or crushed to fragments. With this exception the rocks as far as Hell's Mouth are greenish and bluish slaty beds of the Green Series, which seem to pass up quite uninterruptedly into pebbly slates, these being followed by a quartzite-ridge that runs to Craig Wen.

From evidence already obtained in the western part of the Complex, it is permissible to infer that the pebbly slates and the quartzite form the upper part of the Llanbadrig Series, wherefore there must be a fault or an unconformity here between them and the Green Series. I have not detected either a fault or an unconformity on the coast, where indeed the exposures suggest a passage from the Green Slates into the pebbly group, but the stratigraphy requires a break here, and in this area of compressed beds some faulted junctions so closely resemble bedding-planes as to be easily overlooked. On the map (Pl. XIII) therefore I provisionally insert a fault here.

As this Llanbadrig zone is followed to Porth Wen Bay a second quartzite appears on a lower horizon, south of the pebbly beds. In the south-western part of Porth Wen Bay the rocks are quartzite and quartzose grit interbedded with shaly beds, and resemble the rocks of Porth Padrig.

South of Craig Wen the lower quartzite is succeeded by banded dark siliceous shales, which exhibit tiny faults, and pass locally into quartzite. In places they assume a conglomeratic aspect, which is, however, due to crush, some of the 'pebbles' still showing the same banding as the matrix, but they pass up into beds with numerous true pebbles of quartzose grit, upon which the upper quartzite reposes.

In Porth Wen Bay a cross-fault throws back the southern boundary of the Llanbadrig Series about 100 yards southward, and the disposition of the beds along the eastern side of the Bay is that figured in Pl. XIV (Section 3). This shows the rocks to form an overfolded syncline of the three series (Green, Llanbadrig, and

Llandeilo), each in their proper order, but with many of their component beds cut out and others repeated. The Green Series is followed by Llanbadrig beds of limestone (some of which has been burnt for lime), quartzite and slate, and crush-conglomerates of slate and grit. These beds are faulted, broken, and repeated; the upper beds of this Series and the lower beds of the Llandeilo are wanting, but the Upper Llandeilo Beds are present, as already described, in Porth Pridd (p. 237). The Llandeilo rocks are overthrust by slaty beds of the Llanbadrig Series with some quartzite, and the latter in their turn are overridden by slates belonging to the Green Series.

The Llanbadrig rocks in this section only fringe the Bay, being cut out inland by a transverse fault which brings them against the Green Slates. Some of the usual slaty beds, with patches of limestone and quartzite, and a quartzose sandstone with purple slaty matrix, form a strip below the Llandeilo conglomerates of Mynydd Pant-y-gaseg, but the group is soon faulted out to the east. All that are now left of the Llanbadrig rocks in this direction are a few masses of quartzite and limestone (the latter associated with black shale), involved in the Green Series near Glan-y-don, Bull Bay.

The exposures of Llanbadrig Beds east of the Hell's Mouth Fault seem to confirm the sequence suggested for the western part of the Complex. The highest horizons are seen on the western side of Porth Wen Bay to be a quartzite underlain by pebbly slates which pass down, through slates with some local developments of quartzite, into quartzites and shales with subordinate limestone. On the eastern side and to the south of Porth Wen Bay are rocks of the Llanbadrig Headland type, including a limestone apparently referable to the horizon of the Trwyn y Parc Limestone, and some crush-conglomerates which are probably of the same horizon as those at Trwyn y Parc. From a comparison of the exposures of the whole area the probable succession of the strata comprised under the name of the Llanbadrig Series appears to be as stated below, in descending order, the total thickness being estimated at about 1000 or 1500 feet:—

Bf. Quartzite.
Be. Pebbly slates.
Bd. Slates with grit and quartzite-bands.
Bc. Quartzites, shales, and some limestone (at Porth Padrig, etc.).
Bb. Limestone (as at Trwyn y Parc).
Ba. Grits and slates, usually shattered to a crush-conglomerate.

This interpretation is not without its difficulties and is not stated with complete confidence; it is put forward rather as a working hypothesis, which may be useful in correlating similar rocks in other parts of Anglesey. A small patch of these rocks has been noticed by the present writer along a line of fault south of Mynachdy Lodge, near Llanfair-y'nghornwy, and it seems clear from the descriptions of various writers on Anglesey geology that the Series occurs elsewhere in the island.

The Llanbadrig Series is newer than, and its base may be conformable with, the Green Series. No fragments derived from the latter have been observed in the lower zones of the Llanbadrig rocks, and there is also a close similarity between the Green Slates and a few of the slaty rocks of the Llanbadrig Series which suggests a close connexion between the two groups. It is a fact that the Llanbadrig Beds are found in juxtaposition with several horizons of the Green Series, but the junction is seen to be a fault in some cases, and in other cases where the junction is obscure it seems more reasonable to assume a fault than an unconformity.

On the other hand, one of the highest zones, namely the beds (*Be*) below the highest quartzite, has yielded rock-fragments which, in Prof. Watts's opinion, are 'almost certainly derived from the Green Series.' The best example is a microscopic slide [N. A. 119][1] from the beds below the Porth Llanlliana quartzite, where the fragments are chiefly varieties of phyllite and chlorite-schist. The beds containing them cannot be excluded from the Llanbadrig Series (although they have a distinct resemblance to some of the Llandeilo basal rocks) on account of the quartzite and limestone associated with them. The evidence, as a whole, is therefore in favour of the Llanbadrig Series being unconformable to the Green Series.

As regards the relation of the Llanbadrig Beds to the overlying basal Llandeilo rocks, the occurrence of fragments of limestone and pieces of quartzite in the Llandeilo conglomerates favours the view that the two series are unconformable. But the latter beds cling closely to the quartzite which forms the highest member of the Llanbadrig group, instead of lying indifferently upon the various members of that series; and where this quartzite and the overlying conglomerates are seen together in the cliffs, as at Porth Llanlliana and to the east of Hell's Mouth, they dip at the same angle in apparent conformity, this fact showing that the quartzite-beds must have been horizontal when the Llandeilo conglomerates were laid down. Moreover, when the Llandeilo and Llanbadrig rocks are faulted together, a quartzite is the rock usually found at the junction, and this rock may be seen (as at Ogof Gynfor and near Porth Padrig) even in the midst of Llandeilo ground. It is therefore a moot-point whether there is an unconformity at all between the Llanbadrig and the Llandeilo Series: it is certainly not a conspicuous one. Yet the variation in thickness of the quartzite as it is followed along its outcrop—a point which will be again referred to shortly—could be very conveniently explained by its erosion at the time when the conglomerates were forming.

In short, the evidence of the relations of the upper part of the Llanbadrig Series to the Llandeilo conglomerates is conflicting. No fossils have been found in the Llanbadrig rocks to help us to a conclusion, and no more definite assertion of their age is therefore made than that they are pre-Llandeilo.

[1] The numbers in brackets are those of microscope-slides in my cabinet.

(iii) Further Remarks on the Quartzites.—Some features of the quartzites were discussed by Prof. Watts and myself in our recent paper, but other points, hardly affecting the conclusions arrived at, were deferred by me till the mapping had been completed. These points are, their association with limestone, their variations in thickness, and their relationship to the conglomerates.

Association with Limestone.—In some localities the quartzites are seen to include some limestone, not, however, of great thickness. This may be seen east of Penterfyn, and at the eastern end of the Llanlliana quartzite-ridge. At the latter locality the limestone is composed of highly-contorted laminæ. The limestone enclosed in the quartzite at the western extremity of the same ridge (see p. 670 of my former paper) would be perhaps more accurately described as an interbedded limestone-band locally crushed out. In Porth y Wylfa also a wedge of quartzite includes a thin limestone. Sections taken from some of these limestones show them to be of very fine grain, veined with calcite and sometimes showing silicification [N. A. 123], and the rock between the limestone and the quartzite is in one example [N. A. 130; cliffs above Hell's Mouth] a sandstone with calcareous cement. The limestone-zones seem to be merely inconstant developments, laid down locally in clear water at intervals between the deposition of the sandy material. Their inconstant occurrence may be also partly due to removal by solution or siliceous replacement, and in part to crushing-out by movement. Sediments of intermediate composition, such as ordinarily form calcareous sandstones, would, by the solution of the carbonate of lime and its replacement by silica, become rocks like some of these quartzites whose clastic grains are embedded in a mosaic of quartz.

Rapid Variation in Thickness.—The map shows that the principal quartzite-ridges increase in width of outcrop as they are followed from west to east. This is especially noticeable with the Llanlliana Head and Craig Wen quartzites, where the appearances cannot be altogether explained by faulting. Of the two the Craig Wen quartzite offers the more striking and simpler example. Near Hell's Mouth it is perhaps 30 feet thick, the purple conglomerate above it is certainly not separated from it by a fault, nor is a fault visible at the base of the quartzite; yet at Craig Wen, only $\frac{1}{4}$ mile distant, the quartzite has an apparent thickness of about 200 feet. This point must be considered in connexion with the overlying conglomerates.

Relationship to the Conglomerates.—The Craig Wen quartzite-ridge is overlain and underlain by conglomeratic beds. The overlying purple conglomerate is often bleached near its base and converted into a quartzite which, though not very different in appearance from the quartzite-ridge itself, shows its conglomeratic origin plainly enough, so that there is as a rule no difficulty in determining the junction. Near Craig Wen a lenticle of the quartzite lies surrounded by the conglomerate, and, close by, a great tongue of the latter runs into the former. Also, when the width of outcrop

of the quartzite increases, that of the conglomerate decreases, the united width of the two being fairly constant. Facts such as these point to this quartzite having originated by alteration of the conglomerate, but I have not felt able to adopt such an explanation, the change from the fine-grained homogeneous quartzite to the adjacent conglomerate being too abrupt.

The upper part of the conglomeratic beds which occur below the quartzite sometimes has a pale and quartzitic aspect, but its derivation by alteration from a crushed quartzose slaty and pebbly grit is evident. It may have undergone some silicification from the overlying massive uncleaved quartzite, into which it passes rather abruptly. Layers of this character are occasionally seen interstratified with the quartzite itself.

Near Is-allt the quartzite is again associated with a conglomeratic quartzite which I have mapped as basal Ordovician. The quartzites have a conglomeratic appearance in other localities (for example, see Pl. XIV, Section 2); but in this and some other cases I consider the appearance to be merely the result of brecciation and recementing of the quartzite.

The mode of occurrence of these rocks in the field, as described above, is difficult to explain satisfactorily. Faulting and movement account for some features, as for instance the quartzite-lenticle in the purple conglomerate, the tongue of conglomerate between repetitions of the quartzite, and the cutting-out of most of the conglomerate at Craig Wen; but the swelling-out of the quartzite at Craig Wen is too great to be assigned wholly to movement, though partly an effect of this cause. It is open to us to regard the variations in thickness as the result of erosion of part of the quartzite before the deposition of the conglomerate, a view which has its difficulties; or as an irregularity in the distribution of the original sediment.

While admitting that these quartzites present features not easy of explanation, I adhere to the opinion expressed in my former paper, that these rocks are altered sandstones which are sometimes completely isolated owing to disruption by earth-movements. Ample evidence of their clastic nature is given in Prof. Watts's appendix to that paper; but it is due to Prof. Bonney to state that the sedimentary origin of a 'quartz-knob' near Beaumaris was determined by him so long ago as 1883.[1]

(*c*) Structure of the Northern Complex.

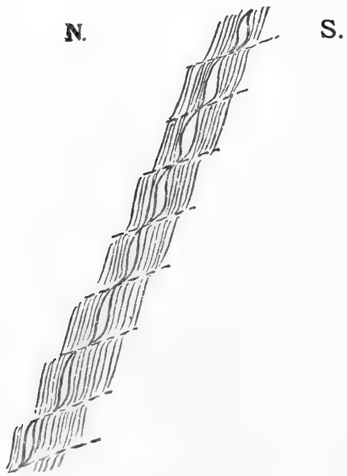
The mapping of the Northern Complex has brought out in fuller detail the overthrusting from a northerly direction which had been previously demonstrated. The area consists of a series of shattered folds, whose deeper synclines are traceable by means of

[1] Quart. Journ. Geol. Soc. vol. xxxix (1883) p. 471; see also Sollas, Sci. Proc. Roy. Dublin Soc. n. s. vol. vii (1892) p. 169.

the Llandeilo outcrops. In spite of the prevalent steep northerly dip, the older rocks are forced up again and again to the surface, so that even the island called the Middle Mouse (Ynys Badrig), which lies beyond the extreme northern point of the coast, is formed of beds not belonging, as might be expected from its geographical position, to the newest group of rocks, but to the oldest or Green Series.

Although from a tectonic aspect the grouping of the faults may be considered as fold-forms, it should be remembered that in this Complex actual folding is quite subordinate to the faulting. The dislocation-planes, both of the thrust- and the normal faults, are usually steep, differing little in direction and amount from the angle of dip. Thrust-planes of a gentler slope are in this part of Northern Anglesey mostly of minor importance, with upthrusts varying from a few inches to a few feet. They are numerous at Pig y Barcud (see Pl. XIV, Section 1) and in the cliffs north of Porth Wen Pier; while in the Green Slates of Trwyn Bychan (Porth Wen Bay) they give a false appearance of bedding (see Pl. XIV, Section 3). Fig. 3 shows the effect of this shear-cleavage on a quartz-vein at the last-named locality.

Fig. 3.—*Faulted quartz-vein in the cliff at Trwyn Bychan (inaccessible, but apparently 2 or 3 inches thick).*



The sequence of the movements which have affected this part of Anglesey since Llandeilo times seems to be as follows:—The strata were first bent into a series of folds. A continuance of the compression, which here acted from a direction somewhat to the east of north, crushed and broke up the folds; produced an east-south-easterly strike, numerous strike-faults, and overthrusting of the beds; caused the minor shearing such as deformed the pebbles of the purple conglomerate (p. 234); and induced the imperfect shear-cleavage at Trwyn Bychan. The east-and-west cleavage which obtains along part of the coast was impressed on the rocks somewhat later by a change in the direction of compression.

The transverse faults of the Hell's Mouth type may be perhaps regarded as later than the strike-faults, since they appear to truncate these; but the transverse fault east of Porth Wen Bay is not easily explicable on this hypothesis, as it does not pass through the planes of overthrust south of Trwyn Bychan. It seems more probable

that this fault, at any rate, has been produced during the great period of movement, and has permitted the folding and faulting to take place independently on either side of the plane of fracture.

The structure of the Green Series and of the Ordovician rocks to the south of them is still very imperfectly known, but when fully worked out the beds will no doubt show a structure similar to that obtaining along the northern coast. From a careful perusal of Prof. Hughes's and Dr. Callaway's descriptions [1] of the Ordovician rocks, and from my own observations on the rocks of the Green Series, it appears to me that the generalized structure of the country from the south of Llanerchymedd to the northern coast is somewhat as represented in fig. 4 (p. 248).

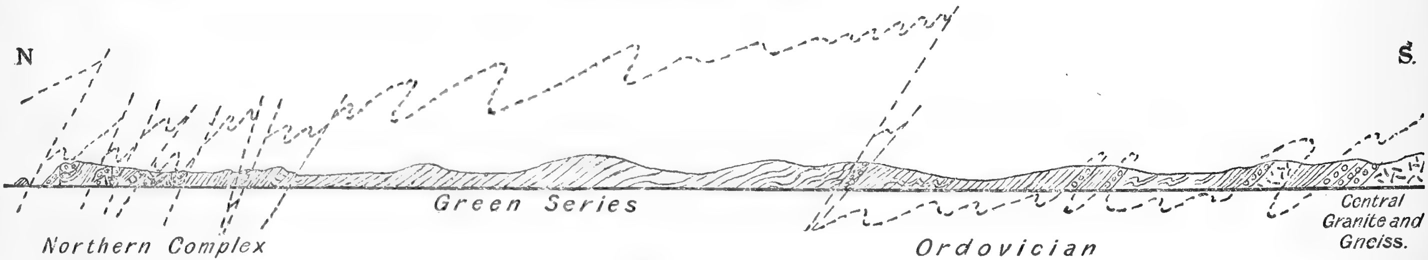
A glance at a geological map is sufficient to show that Anglesey as a whole has undergone other movements than those enumerated in the foregoing paragraphs. In Central and Eastern Anglesey the rocks strike south-westward, and the principal faults run in the same direction (parallel, it may be noticed, to the Hell's Mouth Fault). Was the movement that produced this south-westerly strike contemporaneous with, or later than, the northerly thrust? There is something to be said in favour of both views. The post-Bala and pre-Silurian movement from the south-east which affected the rocks of Caernarvonshire would bring about such a strike; on the other hand, the Carboniferous and Permian strata have the same strike, whence it may be inferred that the movement was later than the pre-Carboniferous northerly thrust, or at any rate was prolonged into Permian times. In either case the northerly thrust was not confined in its effect to the north of the island, as Prof. Bonney and Miss Raisin have observed thrusting from the north in the gabbros and serpentines of the Holyhead district.[2] Whether the two movements were simultaneous or successive, it is clear that the south-easterly one predominates in Southern and Eastern Anglesey, while the northerly movement is predominant in the north of the island. In the intervening area, between Holyhead Bay and Dulas Bay, may be expected a torsion of the beds caused by the interference of the two directions of movement, which, while adding to the stratigraphical difficulties, should prove a fascinating study for the geologist who endeavours to unravel the complex arrangement of the strata.

II. The Intrusive and Associated Rocks of Northern Anglesey.

The following account is limited to such igneous rocks as are found within the Northern District, that is to say within the area north of the Llanfflewin overthrust. A petrographical description of some of these rocks has been already given by Prof. Blake,[3] while their mode of occurrence in the field has been briefly mentioned by Ramsay, Callaway, Blake, Geikie, and other writers. These rocks

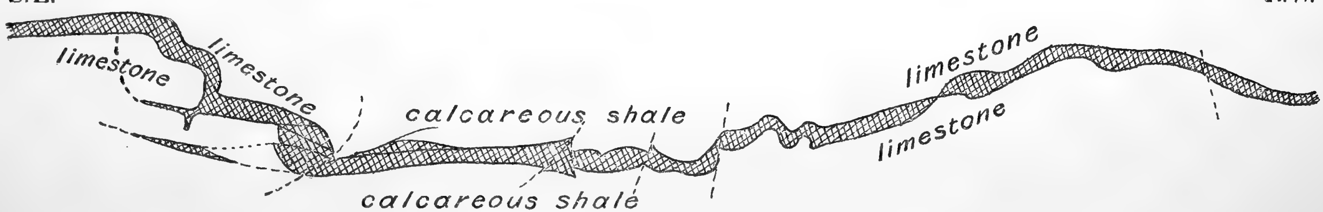
[1] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 16 & vol. xl (1884) p. 567.
[2] *Ibid.* vol. lv (1899) p. 301.
[3] Rep. Brit. Assoc. 1888 (Bath) p. 367.

Fig. 4.—*Generalized section from Central Anglesey to the northern coast, with a suggestion of the structure of the area (semi-diagrammatic).* *See p. 247.*



[Length = about 9 miles.]

Fig. 5.—*Outcrop of a basaltic dyke, near the 'Wishing Well,' on the coast, Llanbadrig.* *See pp. 251 & 252.*



[Average width of dyke = about 18 inches.]

differ widely in age, composition, and texture. They may be conveniently divided into two groups, according as they were injected before or after the last great period of movement which affected the rocks of Anglesey; this classification practically separates them into pre-Silurian and post-Ordovician intrusions.

(*a*) Pre-movement Intrusions.

Granite.—Near the western limit of the district is the granite of Mynachdy, described by Prof. Blake. Another mass occurs beyond the limits of the district at Pen Bryn-yr-Eglwys. As Prof. Blake has pointed out, the granite is usually much crushed, and it appears to be of the same character and age as the great masses of Central Anglesey.

Serpentine and its Associates.— Serpentines occur in several localities in Northern Anglesey among rocks of the Green Series, and in each area they are associated with a purple limestone unknown elsewhere in the district: they also contain bands of ophicalcite. One mass at Tre-gele depicted on the Geological Survey map is not now exposed, but Prof. Blake found the purple limestone there.[1] Another mass is seen in some small quarries, near the Chapel at Llanfechell. The limestone, which lies north of the serpentine, is a red to reddish-purple compact rock, often veined with white calcite; it has been crushed and sheared, and iron-ores occupy the gliding-planes. One specimen [N.A. 100] consists of coarse and fine granular layers, much contorted and sheared together, the finer calcite being full of iron-ore. It effervesces with acid, but not very freely. The serpentine is usually a dull, dark green, compact fibrous rock, contains chrysotile-veins, is occasionally banded, and sometimes brecciated. Fragments of the purple limestone are found in it, and it passes into ophicalcite. The limestone is seen again 200 yards to the south-south-west, where it is associated with ophicalcite-schist [N.A. 106].

Another exposure of these rocks occurs $3\frac{1}{4}$ miles away in a west-north-westerly direction, in a small disused quarry north of Mynachdy Lodge. The purple limestone which occupies the greater part of the quarry is precisely identical with that of Llanfechell. The serpentine lies mainly on the south side of the exposure, but occurs as streaks and patches in the limestone. Near the southern boundary of the serpentine and the schists is a dolerite-dyke, intrusive into the former.

The serpentine is seen once more 600 yards away, on the coast at the western end of Porth yr Ysgraff. The intervening area is covered by Drift, so that it cannot be stated whether or not the rock is continuous with the last-mentioned exposure. The serpentine has here a schistose character, the structural planes dipping in a northerly direction, and varies in colour from green to yellow, with frequent patches and veins of bright red. It passes down

[1] Quart. Journ. Geol. Soc. vol. xliv (1888) p. 517.

into a pale calcareous rock (with tremolite? developed in it) which curves round and bends over a mass of dark rock: this, in part at least, is a hornblendite made up of hornblende, ilmenite, and tremolite or actinolite.

By analogy with those of the Holyhead district these serpentines should be regarded as altered igneous intrusions, but such an origin cannot be affirmed with any certainty, as they show no igneous structure. Their sporadic occurrence is evidence of their being of intrusive nature, but this argument applies with equal force to the purple limestone, which among many square miles of the green phyllites and slates of the northern district is only known in three isolated localities, and then always in connexion with the serpentine.

Whatever the origin of these serpentines and limestones, both are clearly of earlier date than the great movements that affected the area, and the limestone cannot therefore be looked upon as a product of infiltration from any post-Ordovician limestone which may once have overlain this area.

The following notes, kindly supplied by Prof. Watts, are descriptive of some of these rocks:—

[N.A. 115; near Llanfechell Chapel.] Ophicalcite. Masses of granular calcite and serpentine mixed together. The calcite contains one broken crystal of picotite. The serpentine occurs in colourless, brightly-polarizing crystals, set in an almost isotropic, dull-green serpentine. From these patches the blades penetrate into the surrounding calcite and into and between the crystals and grains of it in the same way as the silica in N.A. 123 (see p. 244). Magnetite is present as usual.

[N.A. 19; same locality.] Ophicalcite. Streaks and large patches of serpentine set among grains and often rhombohedra of calcite (or dolomite). Smaller patches of serpentine, generally associated with more coarsely crystalline calcite, and often with aggregates of magnetite. Some of these patches consist of calcite and magnetite alone.

[N.A. 106; south-south-west of the above.] Ophicalcite-schist. Fine intermixture of serpentine and calcite, the latter in small grains set in a felt of serpentine; minute 'augen-structure.'

[N.A. 78; north of Mynachdy Lodge.] Coarse and fine granular limestone contorted and mixed together; some folia filled with colourless serpentine; much interstitial muscovite.

[N.A. 102; Porth yr Ysgraff.] Foliated serpentine. One bit of picotite. Some bands rather more coarsely crystalline than the rest.

Basaltic Dykes.—Two dykes, crushed and broken by earth-movements, were brought to notice in my previous paper[1]; they occur in the crush-zones of the Northern Complex. A third dyke of similar appearance has been found on the coast west of Penrhyn.

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 666.

(*b*) Post-movement Intrusions.

The later dykes and bosses are of both acid and basic composition, and not infrequently both acid and basic magmas are found to have been injected into the same fissure, forming composite dykes.

Basic Dykes.—A number of these are shown on the Geological Survey map cutting through the beds of the Green Series and extending with a general parallelism in a south-easterly or east-south-easterly direction to the boundary-thrust, where they cease. They are best exposed on the coast, their inland course being usually concealed by the cover of Glacial Drift and soil. They are more numerous than the Survey map shows, but this is a matter of small topographical importance, as they rarely exceed 5 or 6 feet in width, most of them being only 2 or 3 feet across. I counted over twenty of these dykes along the coast in the western part of the district between the fault at Porth Newydd and Trwyn Cemlyn, and they occur with about the same frequency from Cemlyn Bay to Porth Wnol. In the crush-zone at Penrhyn and around the harbour at Cemaes they are more closely grouped together; from Cemaes to Llanbadrig they are rare, but in the broken rocks near Llanbadrig Church they become again numerous. With the exception of one near Ogof Gynfor, I have detected no dykes between Llanbadrig and Bull Bay.

That the dykes at Penrhyn are of later date than the period of crushing has been pointed out by Sir Archibald Geikie,[1] and those at Llanbadrig show similarly their unmistakable post-movement age. The course of one of these latter is represented in fig. 5 (p. 248), from which it will be observed that the dyke is fairly straight, but fluctuates somewhat in width, and the flow of the magma has been influenced to some extent by the joints and other structural planes of the rocks into which it was injected.

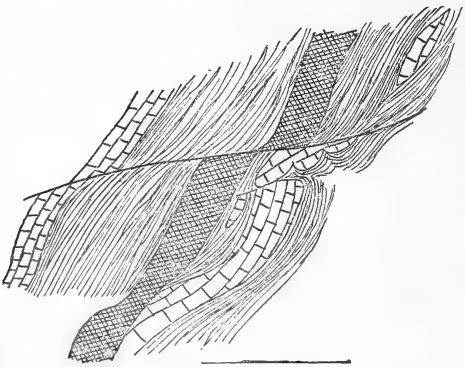
I have not attempted to trace the dykes in the neighbourhood of the boundary-thrust, but, according to the Geological Survey map, though they pass up to the thrust they do not extend beyond it. As they are of later date than the thrusting this is remarkable, but possibly their absence may be merely apparent, owing to the poorness of exposures in the soft Ordovician rocks south of the Green Series. But the dykes really seem, for some reason as yet unexplained, to have usually avoided Ordovician beds; and I have seen only one example, between the cliff of graptolitic shale in Porth Padrig and the Vicarage, where a dyke is in contact with Llandeilo rocks.

Yet, although of later date than the last period of great movement in Anglesey, these dykes yield some evidence of minor movement since their injection. One of the Llanbadrig dykes is truncated by a small thrust from the north (fig. 6, p. 252), but it seems possible to explain it as the result of disturbance caused by the rather later injection of a neighbouring fissure. A microscope-section [N.A. 124]

[1] Geol. Mag. 1896. p. 481; see also Quart. Journ. Geol. Soc. vol. lv (1899) p. 660 (fig. 9) & p. 666.

cut from a junction of the basalt with the Llanfechell Grit south of Groes-fechan shows that the basalt has undergone some shearing parallel to the junction; but with these exceptions I have observed no effects of pressure on these rocks.

Fig. 6.—*Faulted basaltic dyke, near the old limestone-quarry on the coast, near Llanbadrig Church. See p. 251.*



[Width of dyke = about 15 inches.]

These basalts and dolerites are usually fresh-looking black rocks with only a thin weathered crust, are as a rule fine-grained, and sometimes have large phenocrysts of felspar. Some specimens are rich in pyrites, others exhibit small spheroidal amygdules filled with calcite and chlorite. Some upstanding bosses of coarse ophitic dolerite are found, in which the augite has been converted to hornblende. It is uncertain, though not unlikely, that these date from the same period. The Llanbadrig dykes already mentioned weather differently from most of the basalts; they are externally ferruginous, are more deeply weathered, and below the crust are quite pale in colour. The microscope shows them to be almost tachylytic.

The following notes, descriptive of the microscopical structure of these rocks, have been kindly supplied by Prof. Watts:—

[N.A. 112; Llanbadrig: dyke represented in fig. 5, p. 248.] Once a glassy basalt, with large phenocrysts of felspar and smaller ones of felspar and probably augite, all highly decomposed. Altered glassy groundmass full of skeleton-crystals of magnetite.

[N.A. 113; same locality: dyke represented in fig. 6.] Porphyritic basalt. Groundmass brown and glassy, full of microliths of magnetite and of long, slender felspar-microliths.

[N.A. 51; between Porth Padrig and the Vicarage.] Porphyritic basalt or andesite. The porphyritic felspars are well shaped, but have undergone a micaceous alteration. The groundmass is mainly made up of felspar-microliths set in cryptocrystalline interstitial matter.

[N.A. 29; boss between Caerau and Nanner.] Coarse, ophitic, hornblendic dolerite, containing augite.

[N.A. 125; south of Groes-fechan.] A porphyritic basalt with phenocrysts of decomposed felspar and pseudomorphs after olivine. Groundmass very fine-grained and possibly glassy, with magnetite- and felspar-microliths. The rock includes some highly corroded grains, apparently xenoliths, of quartz.

Acid Intrusions.—The acid dykes are rarer than the basic, but have a greater average width. They are granophyres, quartz-porphyries, and microgranites; for field-description they may be spoken of generally as felsites. A group of them is shown, on the Geological Survey map, south of Llanfechell, coursing in the same direction as the basic dykes, and, like the latter, terminating at the boundary-thrust. I have observed one on the coast at Trwyn Cemlyn, and others near Cemaes Pier and at a few localities inland. In no instance, however, have I found them to be injected into any other rocks than those of the Green Series. Even at Cemaes Pier, though they strike at the neighbouring crush-conglomerate and limestone-masses of Penrhyn, they fail to penetrate them.

From evidence which will be stated below, I infer that these acid dykes were injected before the basalts, but their difference of age may be slight; and seeing that, so far as I have examined them, they yield no evidence of crushing, I regard them as 'post-movement' intrusions. These rocks weather with a white crust, and have a splintery fracture. They are pale grey, bluish, brown, or flesh-coloured, with needles of a green hornblendic mineral, and sometimes contain corroded crystals of quartz. Some of the dykes are beautifully spherulitic, as described by Prof. Blake.[1]

The following notes have also been supplied by Prof. Watts:—

[N.A. 23; Bwchanan, south of Llanfechell.] A beautiful spherulitic felsite. Groundmass minutely granular or cryptocrystalline. Fibrous chlorite occurs between the spherulites, and long needles, once probably actinolite, run through the spherulites. Felspar- and also hornblende-phenocrysts. Some epidote is present, and a pink, pleochroic mineral occurs in some of the spherulites.

[N.A. 127; ridge north of Coeden.] Granophyre. Large phenocrysts of quartz and felspar. Groundmass holocrystalline, made up of moderately large grains of quartz, felspar, and micropegmatite.

[N.A. 109; Hafod-onen.] Granophyre. Orthoclase-phenocrysts, often twinned on the Carlsbad plan. Many of these phenocrysts show an internal structure resembling that of micropegmatite, and most of them are encrusted and completed by a granophyric growth. The structure of this rock is very beautiful, and it has been fully described by Prof. Blake (*loc. cit.*). See also p. 254.

Composite Dykes.—The injection of a fissure with both acid and basic material is well known from Prof. Judd's descriptions of the composite dykes of Arran,[2] and similar dykes are known to occur in Ireland (County Down).[3] Hitherto, so far as I am aware, they have not been recognized in Southern Britain, and their occurrence in another portion of the Irish Sea area should therefore prove of some interest.

My attention was first attracted to the association of acid and

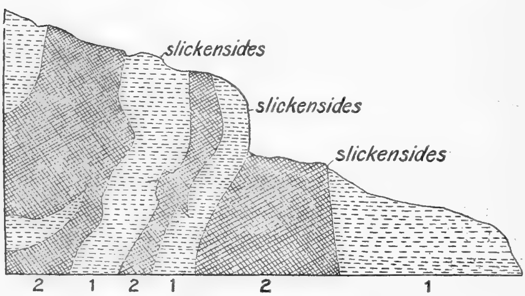
[1] Rep. Brit. Assoc. 1888 (Bath) p. 410.
[2] Quart. Journ. Geol. Soc. vol. xlix (1893) p. 536.
[3] G. A. J. Cole, Trans. Roy. Dublin Soc. ser. 2, vol. v (1894) p. 239.

basic material by the occurrence of a piece of basalt clinging to the side of a felsite-dyke which lies a short distance south of Cemaes Pier. Basalt was found again in contact with felsite north of the pier, and towards low-water mark a third felsite-dyke was discovered which had a narrow basalt-dyke on each side of it. The basic material seemed to be intrusive into the acid. Examples of these composite dykes have since been observed in various parts of the northern district of Anglesey.

In a field near the road south of Groes-fechan is a felsite-dyke, about 20 feet wide, easily discernible by its white crust. Clinging closely to its northern boundary, and sometimes forming small bays in it, may be noticed patches of basalt. Midway between this dyke and Cefn-côch Factory is a rounded rocky knoll in a field: its sides are evidently basic, but the centre of the mass is a felsite.

A good example of a composite dyke is seen near the serpentine on the road from Llanfechell Chapel to Llyn Geirian. An excavation has been made, in a small garden by the roadside, into one of these dykes. The relationship of the two magmas is shown in fig. 7; the basic, which is distinctly intrusive into the acid portion (a granophyre), has worked its way along joints and cracks, and has caught up fragments of the acid rock. Slickensides occur on both acid and basic parts. This is the only acid dyke that I have found which shows complete invasion by the basic; in the other cases the basic material has been merely 'insinuated' along the edges of the dyke.

Fig. 7.—*Section in the composite dyke, west of Llanfechell.*



1 = Granophyre; 2 = Basalt.

[Width of the part shown = about 16 feet.]

One more example may be cited. At Hafod-onen, south-west of Amlwch, is a quarry in a beautiful granophyre described by Prof. Blake.[1] This forms a boss rather than a dyke. It has a width of 24 feet, and between its southern face and the country-rock is a 2-foot dyke of basalt. On its northern side it is seen again at intervals to be in contact with a basaltic rock. The junction of the latter is not very straight, nor does it always touch the granophyre.

The dykes south of Llanfechell have not been traced far along

[1] Rep. Brit. Assoc. 1888 (Bath) p. 410; see also the description on p. 253 of microscope-section N.A. 109.

their course. They do not exhibit a continuous outcrop, but are traceable at intervals along their line of strike. Followed in this way, felsite is seen sometimes alone, sometimes accompanied by basalt; sometimes again there is basalt and no felsite.

From a consideration of the appearances in the field, so far as I have been able to observe them, it seems to me that both felsites and basalts were intruded at a time, subsequent to the great period of unrest in Anglesey, when minor movement was taking place and new fissures were forming; further, that the felsites were injected early while the fissuring was imperfect and incomplete, and the basalts later when the fissures were more numerous and more continuous. This will account for the less frequent occurrence and the gaps in the continuity of the felsites; for the later injection of the basalts; and for the predominance of the latter over the former. How it is that both acid and basic materials were at hand is a question into which I do not propose to enter.

The basic dykes appear to be of the same character as those with a general similar direction in other parts of Anglesey, such as the south-east, where some are intrusive into the Carboniferous Limestone. One 'greenstone'-dyke is stated by Ramsay[1] to penetrate the Coal Measures, but not to pass into overlying Permian strata. This suggests a post-Carboniferous and pre-Permian age for the post-movement basalts of Northern Anglesey—an age consistent with the evidence of minor movement which they afford.

I have to thank Prof. W. W. Watts, M.A., Sec.G.S., for his great kindness in again undertaking the microscopical examination of the rocks, and for allowing me to embody some of his notes in this paper.

EXPLANATION OF PLATES XIII & XIV.

Plate XIII.

Geological Map of the Northern Complex of Anglesey, on the scale of 4 inches to the mile.

Plate XIV.

Section 1.—Along the coast from Cemaes Bay to the Graptolitic Shales of Porth Padrig (length = about $\frac{3}{8}$ mile).

Section 2.—Along the coast from Llanbadrig Point to near Llanbadrig Church (length = about 350 yards).

Section 3.—Along the eastern side of Porth Wen Bay, and a short distance inland (length = about $\frac{1}{2}$ mile).

Discussion.

The Rev. J. F. Blake said that he had listened with much interest to the paper, which contained many interesting observations that had not been made before. He drew attention to the very numerous 'faults' which were introduced by the Author both in his map and in his diagrams, and thought that they suggested an explosion from

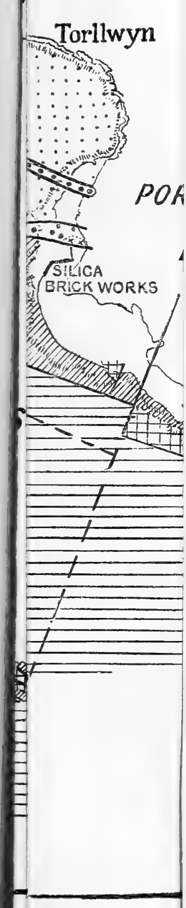
[1] Mem. Geol. Surv. 'Geol. of N. Wales' 2nd ed. (1881) p. 264.

below. One of the slides also that had been shown on the screen seemed to represent a most typical agglomerate; so that he doubted very much whether the group which the speaker had called the 'volcanic group' could have been possibly produced by normal deposition and dislocation. The association of limestone, or ophicalcite, with serpentine was seen elsewhere in the island, and appeared to be a not unnatural result of the subjection of the latter to strain, with subsequent access of heated water.

Mr. Barrow called attention to the close resemblance of these rocks with those already found by Mr. Greenly in Anglesey, and also with those occurring along the Highland Border in Kincardineshire and shown on Sheet 66 of the Geological Survey map of Scotland. Mr. Peach had suggested that these Scottish rocks were of Arenig age, as they bore a singular likeness to the basic igneous rocks and associated cherts of the Southern Uplands. The map shown by the Author suggested a belt of overthrusting, and that had proved to be the relation of the Highland schists to the Border rocks of doubtfully Arenig age. With regard to the limestone of doubtful origin, it might be worth noting that at Garron Point, near Stonehaven, a thick dyke-like mass of ferruginous dolomite had formed in the line of the Highland Fault, and there could be no doubt that this calcareous rock was due to the material set free by crushing the minerals in the mass of basic igneous rock of supposed Arenig age which occurs close to the Fault.

Mr. Greenly congratulated the Author upon his results, which would certainly be of great value in the future investigation of that difficult region. With regard to the Llanbadrig Series, he thought it highly probable (although he had not yet worked in the north of Anglesey) that these rocks would prove to be identical with a group of rocks that he had traced for some miles in other parts of the island. The behaviour of these quartzites and limestones was certainly anomalous, and might prove to be not wholly, though still very largely due to crust-movements. The characters of the dykes, diagrams of which had been shown upon the screen, did not appear to resemble those of the later dykes of the island, which had been hitherto regarded as of post-Carboniferous, but pre-Permian age.

The Author thanked the speakers for the kind way in which they had received the paper. With regard to the numerous faults shown on the map, many were revealed by the coast-sections, others were necessitated by the stratigraphy, and some were inferred. He quite agreed with Mr. Greenly that the quartzites were very puzzling, and looked forward to very important results from the latter's own field-work in Anglesey. The lithological resemblance pointed out by Mr. Barrow of some of the Anglesey rocks to those of the Highland Border was interesting. Some day it might be possible to attempt a correlation of these widely-separated areas.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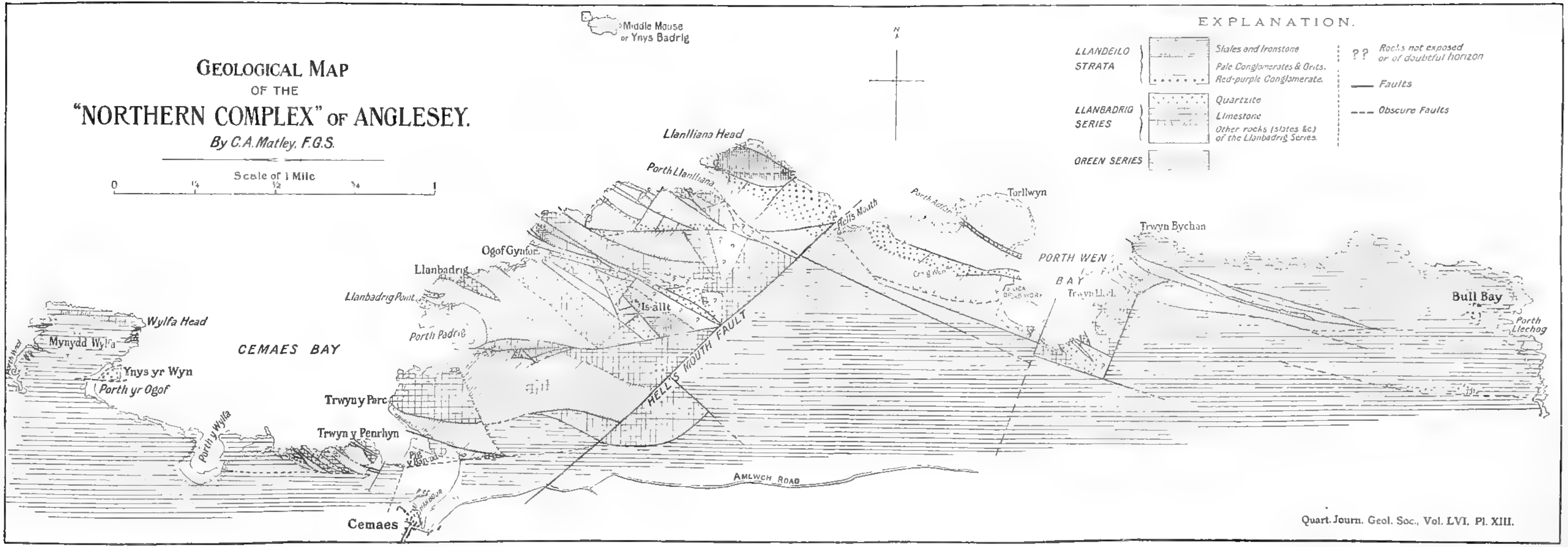

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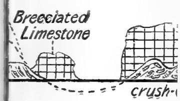

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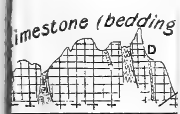

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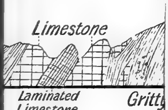
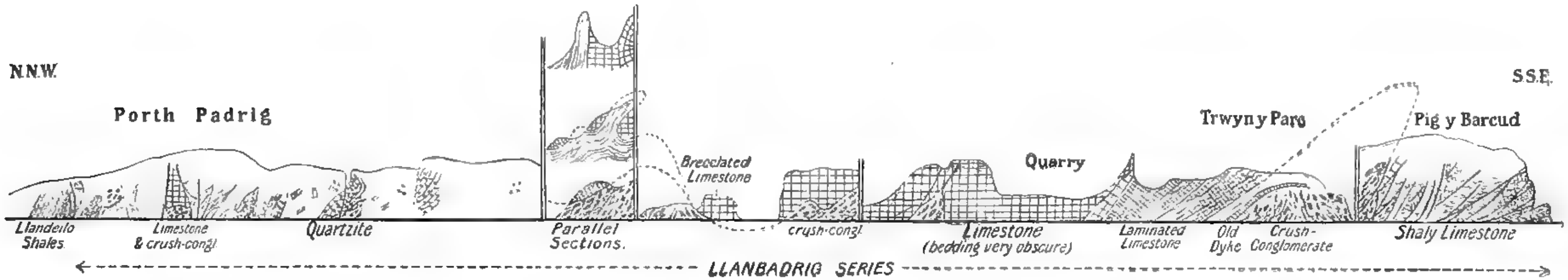
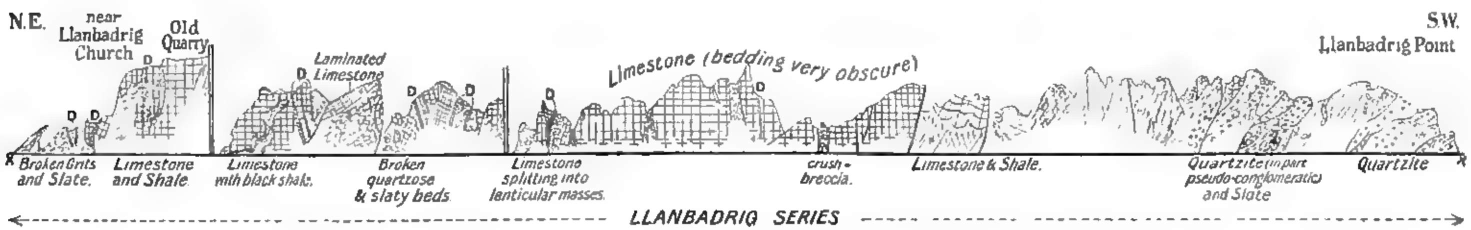


ale.

Section 1.—*Along the coast from Cemaes Bay to the Graptolitic Shales of Porth Padrig: length = about $\frac{3}{8}$ mile.*

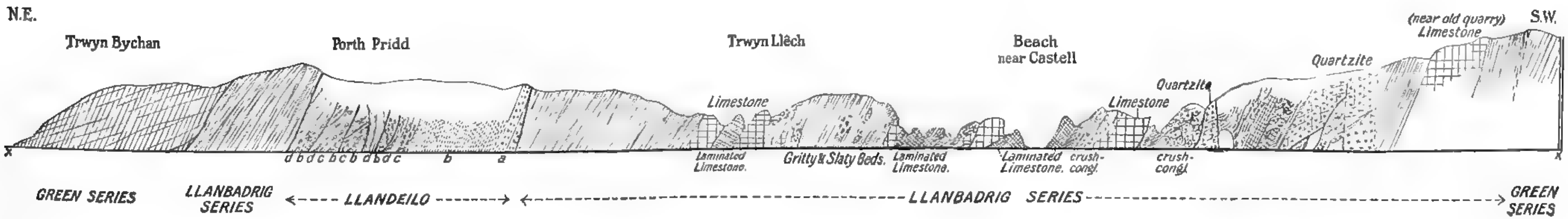


Section 2.—*Along the coast from Llanbadrig Point to near Llanbadrig Church: length = about 350 yards.*



[The three portions of the above section overlap slightly. D = Post-movement basalt-dykes.]

Section 3.—*Along the eastern side of Porth Wen Bay, and a short distance inland: length = about ½ mile.*



a = Grits. *b* = Quartzose shale. *c* = Ironstone. *d* = Argillaceous shale.

14. Foraminifera *from an* Upper Cambrian Horizon *in the* Malverns; *together with a* Note *on some of the* Earliest-known Foraminifera. By Frederick Chapman, Esq., A.L.S., F.R.M.S. (Communicated by Prof. T. T. Groom, M.A., D.Sc., F.G.S. Read February 7th, 1900.)

[Plate XV.]

Occurrence.

The foraminifera here described were found in a shaly limestone which Prof. Groom obtained 'from the débris of a small ridge composed of black shales, with intercalated basalts, which forms a spur on the north-west side of Chase End Hill. The locality is a short distance south of the village of Whiteleaved Oak. In the same specimens of limestone were found traces of Oboloid brachiopoda, and of what appear to be minute gasteropoda, bivalved crustacea or mollusca, and other fossils. The rock belongs to the well-known and widely-spread zone of *Sphærophthalmus*, *Peltura*, and *Ctenopyge*, which in Britain forms the upper half of the Dolgelly Beds or Upper *Lingula*-Flags.'[1]

So far Prof. Groom has been unable to find the rock in place, although there can be no doubt, he informs me, that it occurs not many yards away from the spot where it is now found.

On examining the limestone with a pocket-lens, Prof. Groom noticed a number of small bodies, some of which, when looked at under a high power, had the appearance of foraminifera. Thereupon a thin slice of the rock was prepared, which revealed to him the presence of undoubted foraminifera.

The specimens, courteously placed in my hands by Prof. Groom for description, have been sliced; and they have yielded a few forms other than *Spirillina*, which was the first one seen. Some pieces of the limestone are dark or nearly black, while others are whitish and speckled over with minute dark-blue spots. When thin sections of either variety of limestone are examined, they are seen to be remarkably full of organic remains, chiefly *Spirillina* (see Pl. XV, fig. 1), together with sections of echinoderm-spines, ostracod-tests, and occasionally sponge-spicules (?). The black limestone appears to show the foraminifera in the best state of preservation.[2]

Besides the *Spirillinæ* other foraminiferal remains occur in the limestone, but these are very rare; and it was only by examining a considerable number of thin slices of the rock that the few forms here gathered together could be discovered. In nearly all cases traces of the finely tubulated and hyaline structure of the test can be seen.

[1] For these notes of the occurrence of the rock I am indebted to Prof. Groom.
[2] See Prof. Groom's map, pl. xiii, in Quart. Journ. Geol. Soc. vol. lv (1899).

The tests of the foraminifera are infilled with a crystalline substance, which is broken up or traversed in all directions by cracks. In the examples of *Spirillina* the cracks often extend from wall to wall nearly at right angles to the surface, so that at first sight this might give rise to a false impression of septation within the tubular shell. A little careful study, however, will convince the observer that these are simply cracks, and therefore quite a secondary structure.

Description of the Forms.

The determinations of the various forms given in this paper are as near as it is possible to make them, from a mere outline of the test seen in section; but the structure preserved here and there has been of some assistance.

Family **LAGENIDÆ.**

Subfamily LAGENINÆ.

LAGENA, Walker & Boys.

LAGENA LÆVIS (Montagu). (Pl. XV, fig. 2.)

Vermiculum læve, Montagu, 1803, 'Test. Brit.' p. 524; *Lagena lævis* (Montagu) Brady, 1884, Chall. Rep. vol. ix, p. 455 & pl. lvi, figs. 7–14, 30.

Several examples, closely resembling that figured, occur in the Malvern limestone. The species has been previously recorded from beds as old as Silurian (Wenlock Limestone), and its range extends throughout most of the fossiliferous strata up to recent times.

The Cambrian examples measure about $\frac{1}{100}$ inch in length, being smaller than the recent specimens in the ratio of 1 : 1·6.

LAGENA APICULATA (Reuss). (Pl. XV, fig. 3.)

Oolina apiculata, Reuss, 1850, Haidinger's Naturwiss. Abhandl. vol. iv, p. 22 & pl. i [ii], fig. 1; *Lagena apiculata* (Reuss) Brady, 1884, Chall. Rep. vol. ix, p. 453 & pl. lvi, figs. 4, 15–18.

The earliest record of this species dates from the Lias.

Our specimens are slightly smaller than other known examples from later deposits. The species is very rare in the limestone from the Malverns.

LAGENA OVUM (Ehrenberg). (Pl. XV, fig. 4.)

Miliola ovum, Ehrenberg, 1843, Monatsber. k. Preuss. Akad. Wissensch. Berlin, p. 166; *id.* 1854, 'Mikrogeologie,' pl. xxiii, fig. 2, pl. xxix, fig. 45 & pl. xxxi, fig. 4; *Lagena ovum* (Ehrenb.) Brady, 1884, Chall. Rep. vol. ix, p. 454 & pl. lvi, fig. 5.

This species has been hitherto known from beds as old as the Lower Lias, and it continues to the present day.

The specimen here figured (the only one found) is of the same proportionate size, compared with the recent specimen figured by Brady, as *Lagena lævis* was with the recent form previously mentioned. The specimen under notice appears to show traces of an entosolenian orifice.

Subfamily NODOSARIINÆ.

Nodosaria, Lamarck.

? Nodosaria (Glandulina) sp. (Pl. XV, fig. 5.)

Cf. *Glandulina pygmæa*, Terquem, 1866, 'Foram. du Lias' 6ᵐᵉ Mém. (Acad. Imp. Metz) p. 478 & pl. xix, fig. 6.

It is obviously difficult to say with certainty to what genus or subgenus this specimen belongs. Terquem's figure above quoted seems to come nearest to it in outline. In our specimen only two chambers are present, but in the Liassic specimen there are three.

Nodosaria (Dentalina) abnormis ? (Reuss). (Pl. XV, fig. 6.)

Dentalina abnormis, Reuss, 1863, Sitzungsb. k. Akad. Wissensch. Wien, vol. xlviii, pt. i, p. 46 & pl. ii, fig. 24.

This specimen appears to belong to the *Dentalina* subsection of the genus *Nodosaria*, and in outline is perhaps best matched by Reuss's *D. abnormis.* The apertural extremity is situated hardly far enough to the side for a typical *Marginulina*, although this would depend upon the plane in which the specimen happens to be cut. As regards *Vaginulina*, the chambers are probably too much inflated for it to be related to that genus.

Nodosaria (*Dentalina*) *abnormis* is known from Cretaceous and Tertiary deposits.

Marginulina, d'Orbigny.

Marginulina soluta (?) Reuss. (Pl. XV, figs. 7 & 8.)

Marginulina soluta, Reuss, 1860, Sitzungsb. k. Akad. Wissensch. Wien, vol. xl, p. 206 & pl. vii, fig. 4.

The two specimens (one fragmentary) here figured from the Malvern shaly limestone approach the above-quoted form in general outline: the suture-lines being nearly at right angles to the long axis of the test, with the swollen initial, and subsequent full and unequal chambers. *M. soluta* is known from the Cretaceous.

Cristellaria, Lamarck.

Cristellaria acutauricularis ? (F. & M.). (Pl. XV, fig. 9.)

Nautilus acutauricularis, Fichtel & Moll, 1798, 'Test. Micr.' p. 102 & pl. xviii, figs. *g–i*.

In outline the Cambrian specimen resembles a Cristellarian of the *Cr. acutauricularis* type; but the chambers are remarkably few in number, there being apparently only four in the specimen under notice. The specimen has a very perfect outline.

Family **ROTALIIDÆ.**

Subfamily SPIRILLINÆ.

Spirillina, Ehrenberg.

Spirillina Groomii, sp. nov. (Pl. XV, figs. 1, 10 & 11.)

Test discoidal, convex on the superior, and concave on the inferior

face; consisting of a coiled tube, which is reniform in section owing to the inner surface of each whorl being impressed, as it were, against the rounded edge of the previous whorl; usually having four turns to the whole coil, but sometimes as many as five or even six. The coiled tubular shell often commences with a spherical chamber, which sometimes appears to be partly divided from the rest of the shell. In places the shell-wall is seen to be finely perforate. Average diameter = $\frac{1}{120}$ inch.

The above form differs materially from the well-known species *Sp. vivipara* of Ehrenberg[1] in having a concavo-convex form of test. The tube forming the coils of the disc is also more inflated than in *Sp. vivipara*, the Cambrian examples showing the tube to be higher than broad in vertical section.

Another species, *Sp. obconica* of H. B. Brady,[2] possesses the concave feature of the disc, but it is invariably ovoid in outline.

As regards the number of whorls, the manner in which the coils are enwrapped, and the presence of a conspicuous primordial chamber, we can compare the *Cornuspira crassa* of Zwingli & Kübler,[3] which appears to be a true *Spirillina*, from the Callovian beds of the Swiss Jurassic.

The *Spirillinæ* which occur in the Cambrian limestone of the Malverns are in a very good state of preservation, considering the fragility of the test. Where there are valves of molluscs cut through in section, they are seen to be filled, in many cases, with the tests of *Spirillinæ* crowded together, to the exclusion of other material.

The genus *Spirillina* appears to have been hitherto unknown from beds older than the Jurassic. At the present day the genus is characteristic of fairly shallow and muddy deposits, or of areas where calcareous accumulations are sparingly present.

Note on some of the Earliest-known Foraminifera.

The oldest foraminifera of which we have any record are perhaps those which have been figured and described by Dr. L. Cayeux[4] from quartzites and phthanites of pre-Cambrian age in Britanny. These bodies are subspherical or globular, and conjoined in many instances; they bear upon their surfaces blunt spines or processes, and their walls are finely perforate. Their excessively minute size, however, renders it very difficult to say with certainty that they belong to this particular group of organisms, for the largest of the chambers measure only 10 μ ($\frac{1}{2500}$ inch) in diameter.

[1] Abhandl. k. Preuss. Akad. Wissensch. Berlin, 1841, p. 443 & pl. iii, fig. 41.

[2] Quart. Journ. Micr. Sci. vol. xix (1879) p. 279 & pl. viii, figs. 27 *a*, *b*; see also Chall. Rep. vol. ix (1884) p. 630 & pl. lxxxv, figs. 6 & 7.

[3] 'Foram. d. schweiz. Jura' Winterthur, 1870, p. 19 & pl. ii, fig. 2 (Callovien); see also Jones, Quart. Journ. Geol. Soc. vol. xl (1884) p. 770 & pl. xxxiv, fig. 13.

[4] 'Sur la Présence de Restes de Foraminifères dans les Terrains précambriens de Bretagne' Ann. Soc. Géol. Nord, vol. xxii (1894) pp. 116–19.

Next in order of age are the remains of foraminifera figured by Ehrenberg[1] from the so-called 'Silurian clay' near St. Petersburg. The blue clay of the Baltic Provinces is now known to belong to the Lower Cambrian, since it underlies the *Olenellus*-beds. The foraminiferal remains are in the form of glauconite-casts, and seem referable to the genera *Verneuilina*, *Bolivina*, *Nodosaria*, *Pulvinulina*, and *Rotalia*.

The same author had also previously described[2] many glauconitic casts of foraminifera, etc., from various formations, including some which he had found in the glauconitic sandstone near St. Petersburg, but of these the only definite forms appear to be two specimens of a *Textularia* near to *T. globulosa*, Ehrenb. and a *Rotalia?* (figs. 1 *a*, 1 *b*, & 1 *c* on pl. vi, *op. cit.*).

[The occurrence of foraminifera in the Cambrian of Siberia has been recorded by A. de Lapparent.[3] The limestone containing these organisms is found on the plateau traversed by the Olenek, after its confluence with the Argasala. *Dikellocephalus* is found in these beds, where the limestones become oolitic on account of the numerous foraminifera included in them, and recalling those of the glauconite-beds of the Baltic. On the Tonguska similar limestones contain glauconite.—March 15th, 1900.]

The remains of foraminifera have also been detected by Messrs. W. D. & G. F. Matthew in the Cambrian rocks of Southern New Brunswick. They were first found by Mr. W. D. Matthew in phosphatic nodules from the Acadian or lowest division of the St. John Series.[4] The specimens have since been described by Mr. G. F. Matthew, together with many other fossils forming 'the *Protolenus*-fauna.'[5] The foraminifera are referred to the two genera *Orbulina* and *Globigerina*, and seven new species are described.

In the Ordovician system the shales above the Bala Limestone at Guildfield, near Welshpool, contain foraminifera according to the late Walter Keeping,[6] who also gave further information on the foraminifera of the Llandovery beds.

Foraminifera were first noticed in the slates of Cwm Symlog (Llandovery) by Prof. J. F. Blake,[7] who compared the hollow casts with *Dentalina communis*, and referred to other uncertain forms. Subsequently Walter Keeping[8] further investigated these slates and recorded from them *Dentalina*, *Rotalia (?)*, and *Textularia*.

[1] 'Ueber andere massenhafte mikroskopische Lebensformen der ältesten silurischen Grauwacken-Thone bei Petersburg' Monatsber. k. Preuss. Akad. Wissensch. Berlin, 1858, pp. 324-37 & pl. i.

[2] 'Ueber den Grünsand u. seine Erläuterung des organischen Lebens' Abhandl. k. preuss. Akad. Wissensch. Berlin, 1855, pp. 85–176 & pls. i–vii.

[3] 'Traité de Géologie' 4th ed. Paris, 1900, p. 790. [I am indebted to Prof. Sollas for kindly calling my attention to this notice.]

[4] 'On Phosphate-nodules from the Cambrian of Southern New Brunswick' Trans. N. Y. Acad. Sci. vol. xii (1893) pp. 108–20 & pls. i–iv (in text; foraminifera in sections of nodules).

[5] Trans. N. Y. Acad. Sci. vol. xiv (1895) pp. 109–11 & pl. i.

[6] Geol. Mag. 1882, p. 490.

[7] *Ibid.* 1876, p. 134.

[8] *Ibid.* 1882, p. 490 & pl. xi, figs. 13–15.

In 1888 Dr. H. B. Brady gave an account of four species of *Lagena* from the Woolhope Limestone of the Malverns, etc.[1]

I have also frequently met with *Lagena* in the Wenlock Limestone of Shropshire.

Terquem[2] described four species of *Placopsilina* attached to crinoid-stems from the Upper Silurian of Waldron (Indiana); and in the same paper he also figured and described casts of foraminifera which he referred to the genera *Lagenulina*, *Cristellaria*, *Orbulina*, *Globigerina*, and *Fusulina* from the Devonian of Paffrath.

Foraminifera are, however, rare at the best until the Lower Limestones of the Carboniferous period are reached.

In conclusion my best thanks are due to Prof. T. Rupert Jones, F.R.S., for many valuable suggestions made during the writing of this paper.

EXPLANATION OF PLATE XV.

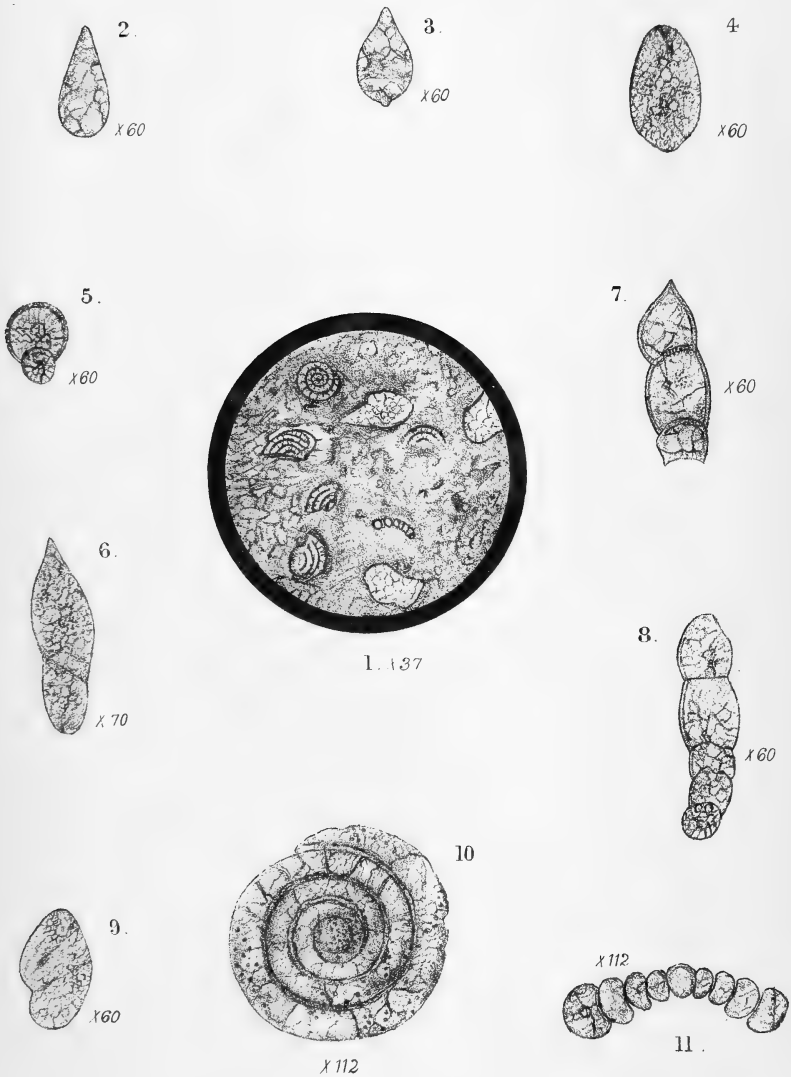
Fig. 1. Shaly limestone with *Spirillina Groomii*, in section. × 37.
2. *Lagena lævis* (Montagu). × 60.
3. *Lagena apiculata* (Reuss). × 60.
4. *Lagena ovum* (Ehrenberg). × 60.
5. ? *Nodosaria* (*Glandulina*) sp., cf. *Glandulina pygmæa*, Terquem. × 60.
6. *Nodosaria* (*Dentalina*) *abnormis*? (Reuss). × 70.
Figs. 7 & 8. *Marginulina soluta* (?) Reuss. × 60.
Fig. 9. *Cristellaria acutauricularis*? (Fichtel & Moll). × 60.
10. *Spirillina Groomii*, sp. nov. Lateral aspect. × 112.
11. The same. Peripheral aspect. × 112.

Discussion.

Prof. Groom expressed his gratitude to the Author for his thorough investigation of the Cambrian foraminifera. Foraminifera had rarely been described from the oldest rocks in any part of the world, and many of the determinations appeared to be uncertain. In Britain no member of this group had been recorded from any horizon older than the Ordovician. *Spirillina* was now proved to be a very old genus. He might add that the Author had recognized foraminiferal casts in the Hollybush Sandstone and Hollybush Quartzite, although, so far, it had been found impossible to determine the genera.

Prof. Sollas congratulated the Author on the results of a very careful and thorough piece of work. It was interesting to observe that in this case lithological and palæontological evidence concurred in indicating that the foraminiferal limestone had been deposited in comparatively shallow water. The account of the distribution of foraminifera in Palæozoic systems with which the paper concluded would prove of great use to students; and in this connexion it might be mentioned that an oolitic limestone, the age of which was shown

[1] 'Note on some Silurian *Lagenæ*' Geol. Mag. pp. 481–84.
[2] Bull. Soc. géol. France, ser. 3, vol. viii (1880) pp. 414–18 & pl. xi.



F. Chapman del ad nat.
A. T. Hollick lith.

Mintern Bros. imp.

FORAMINIFERA FROM THE UPPER CAMBRIAN OF THE MALVERNS.

by associated *Dikellocephalus*, occurred in Siberia and was crowded with various vitreo-perforate foraminifera.

Dr. G. J. Hinde enquired whether any of the characteristic zonal trilobites mentioned had been found in the same detached rock-fragments with the foraminifera, so that their age was incontestably fixed; and whether the Author was satisfied with respect to the nature of the presumed foraminifera from the pre-Cambrian rocks of Britanny.

Prof. Groom, in reply to Dr. Hinde, stated that the characteristic trilobites of the *Sphærophthalmus*-zone had not been detected in the limestone, although they occurred in the associated shales a few yards away. The foraminiferal rock evidently occurred in the heart of the zone.

The Author, also in reply to Dr. Hinde, said that the figures given by Cayeux of foraminifera from the pre-Cambrian rocks of Britanny did not show the structure of the test. Although they bore a general resemblance in outline to some genera with a finely arenaceous shell-wall, as *Hormosina*, yet they must be regarded as of doubtful organic origin.

15. Fossils *in the* Oxford University Museum.—II.[1] *On* Two New Genera *and* Species *of* Crinoidea (*Brahmacrinus ponderosus* and *Cicerocrinus elegans*). By Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S., V.P.G.S. (Read January 24th, 1900.)

[Plate XVI.]

I. *Brahmacrinus ponderosus*, gen. et sp. nov. (Pl. XVI, figs. 1 & 2.)

This somewhat barbarically ornate crinoid is represented in the University Collection by two calyces, which are both devoid of arms and stem. One of the specimens is exceedingly well preserved, and affords a fairly complete knowledge of the structure of the calyx. In the British Museum (Natural History) five specimens of the same crinoid are displayed; these also are calyces without arms or stem. Some of the specimens in the British Museum were obtained from Preston (Lancashire), and some from Yorkshire; those in the Oxford University Museum are from the latter county, where they occur in the Carboniferous Limestone.

The size of the calyx is fairly constant in all specimens, measuring, in that selected for description, 45 mm. in height by 40 mm. in maximum breadth. The dorsal cup is obconic in form, with the apex (corresponding to the base of the crinoid) truncate; the ventral disc is gently convex, and supports an excentric anal tube.

The basals are large, and three in number; two are equal in size and larger than the third, which is the left anterior. The sutures, which are persistent, are not quite symmetric with regard to the radial plates, which they meet on one side of the median line. The basals, like the other plates of the calyx, are much swollen, except immediately over the sutures, which consequently lie at the bottom of a deep groove.

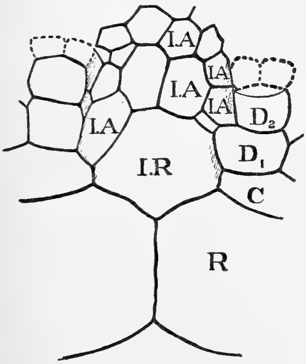
The five radials are also large, 13 mm. in height by 18 mm. in maximum breadth, very thick, but marked by a transverse crescentic depression, which lies in the upper half of each plate. Owing to their contact with more than one interradial plate the outline of the basals is many-sided, usually octagonal. The upper median facet is slightly curved for the reception of the single costal, a much swollen plate, scarcely 9 mm. broad and 5 mm. high. It is completely incorporated in the calyx, forming an integral part of the wall.

The distichals are two in number, of the same breadth, namely, 5 mm., and the first is 3·5 mm. in height; they also form part of

[1] No. I, on Silurian Echinoidea & Ophiuroidea, was published in Quart. Journ. Geol. Soc. vol. lv (1899) p. 692.

the calyx, but the second distichal is not so intimately incorporated with the calyx as the first.

Fig. 1.—*Diagram showing the arrangement of the plates of the calyx of* Brahmacrinus ponderosus. *(×1·5.)*



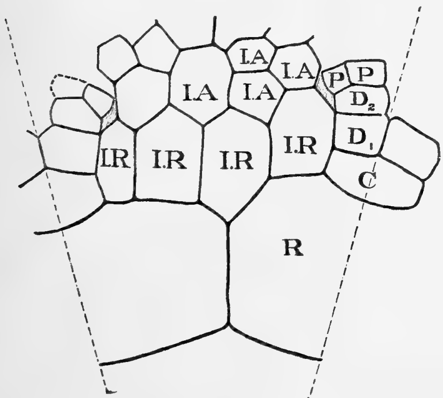
[In this and the succeeding figure the letters have the following meaning :—R=radial ; C=costal ; D_1=first distichal ; D_2=second distichal ; P=palmar ; I.R = interradial ; I.A=interambulacral.]

The first palmars are connected with the calyx by small plates which extend between them and the ventral disc ; their articular surface looks vertically upward and exposes a central canal, from which ridges and furrows extend radiately.

A single interradial, which is in union with two radials below, occurs in each interradius (fig. 1), but in the anal interradius additional plates are present, one on the right of the median interradial and two on the left (fig. 2). These additional plates are united with the radials below ; and those at the extremity of the series, on either side, meet also the costals and first distichals. The single interradial of the other interradii is clearly exposed in one instance only ; it meets the costal and first distichal in front and the costal behind, being separated from the first distichal on this side by a supplementary intervening plate.

The dorsal cup passes gradually into the ventral disc : if we assign all the plates that lie below the ambitus (which runs through the first distichal) to the dorsal cup, then the plates that remain to be described must be regarded as ventral. In the centre of the disc stands a single plate ; next to it on one side are the remains of the excentric anal tube (broken off at a height of 7 mm. from the base) ; the rest of its periphery is bounded by six other plates symmetrically arranged, three on each side of the antero-

Fig. 2.—*Diagram showing the arrangement of the plates in the anal interradius of* Brahmacrinus ponderosus. *(×1·5.)*



posterior plane; surrounding these follow a large number of plates not disposed according to any general law, which complete the plating of the disc; towards the arms they diminish in size, but between the arms, on passing over the ambitus to meet the interradials, they become larger. A series of small plates is continued between the members of each pair of arms, the terminal single plate of the series lying between the second distichals. A single series of minute plates bounds the outer side of the distichals; the first plate of this series is in contact with an interradial; the last overlies the covering-plates of the arm, where these pass into the disc, and terminates in a fractured surface, which exposes the end of a deep groove, somewhat cylindrical in form, excavated in its lower half. This, however, is clearly seen in one instance alone: it may possibly represent a reduced pinnule of the first distichal that has become adherent to the disc.

All the plates of the dorsal cup are very thick and massive, and the sutures, which are very obvious and slightly depressed, lie at the bottom of deep depressions. Most of the plates of the ventral disc are likewise thickened, each into a single tubercle, but small intercalated plates occur, which are devoid of tubercles.

The arms are not preserved, but since the palmars, when present, are found to be united with the disc by marginal plates, it may be presumed that these were not freely movable, and if so the number of the arms would be twenty (5×4).

This remarkable crinoid forcibly recalls in structure and general character the genus *Platycrinus*, with examples of which I found it associated both in the Oxford University Museum and the British Museum. The incorporation of the costal and distichal plates in the calyx affords, however, a very obvious distinction, and there can be little doubt that the present form represents a new generic type, for which I propose the name *Brahmacrinus*, suggested by its resemblance in general appearance to the capital of a column of a Hindu temple.

In some forms of *Platycrinus*, and more particularly in the allied genus *Pleurocrinus*, the costal and first distichal, although projecting beyond the outline of the calyx, are immovably attached to it by adbrachial plates and plates of the ventral disc. But in all such cases it will be found that the costal is completely bounded by the radial and first distichal, and never comes into contact with an interradial plate, as it constantly does in *Brahmacrinus*.

The question will naturally arise as to the family with which *Brahmacrinus* should be associated. If its general appearance reminds us of the Platycrinidæ, the analysis of the calyx as inevitably suggests the Melocrinidæ, from the members of which it is chiefly distinguished by the comparatively small size of the costal and distichal plates; the Melocrinid genus which approaches it most closely is *Stereocrinus*, but this differs not only in the much greater size of the costals and radials, but also by the presence of

slit-like openings at the sides of the arms, which are absent in *Brahmacrinus.*

Brahmacrinus cannot well be assigned to either of the families considered; it is possibly an annectant form, uniting the Melocrinidæ and the Platycrinidæ, and may indifferently be associated with either.

Diagnosis of *Brahmacrinus.*

Calyx having the same composition as in *Platycrinus*, but distinguished by the incorporation of the single costal and the two distichals. The costal and first distichal are suturally united with an interradial of the first series. Anal tube excentric. Anal interradius distinguished from the remaining interradii by additional plates in the first interradial series.

Br. ponderosus. Type-species.

Plates of the calyx thick, those of the dorsal cup especially so, separated by deep grooves, corresponding with the sutures, which are slightly impressed. Radial plates with a crescentic excavation. Arms twenty (5 × 4). Carboniferous Limestone.

II. *Cicerocrinus elegans,* gen. et sp. nov. (Pl. XVI, figs. 3 & 4.)

A single specimen of this elegant little crinoid was found in the Grindrod Collection, bearing the label 'Crinoid, new, ? *Cheirocrinus*,' but without locality or any indication of the horizon from which it was obtained. Since, however, it was placed in a drawer full of Wenlock fossils, and is embedded in a matrix of limestone crowded with Silurian species, it may be referred with great probability to the Wenlock Limestone. The stem, of which 15 mm. is visible, is round and smooth, and composed, at least just below the cup, of a great number of simple disciform ossicles; in a length of 4 mm. twenty discs were counted. In diameter the stem measures 2·5 mm.

The cup is conical, smooth, and devoid of ornament; it measures 13 mm. in height and 6 mm. in maximum breadth, that is, at the upper margin. In general appearance it much resembles an elongated form of *Pisocrinus*, such as *P. pocillum*, Ang.

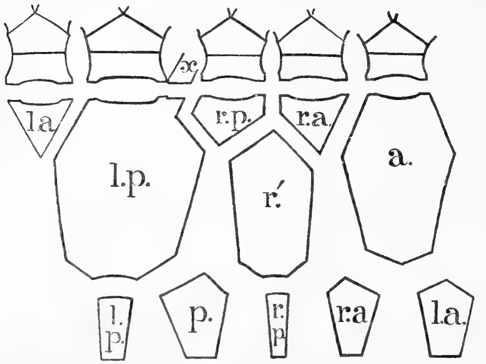
The basals are five in number (fig. 3, p. 268); of these, three are each suturally united above with two radials; the remaining two are each in contact with one radial only: thus the right posterior basal meets the middle of the base of the radi-anal marked R′ in Mr. Bather's paradigm of *Pisocrinus*,[1] and *Az.* by Wachsmuth & Springer; while the left posterior similarly meets the middle of the base of the left posterior radial.

The relative position of the left posterior basal constitutes the

[1] 'Crinoidea of Gotland.—pt. i. Crinoidea Inadunata' Kongl. Svenska Vetenskaps-Akad. Handl. vol. xxv (1893) No. 2, p. 25, fig. 2.

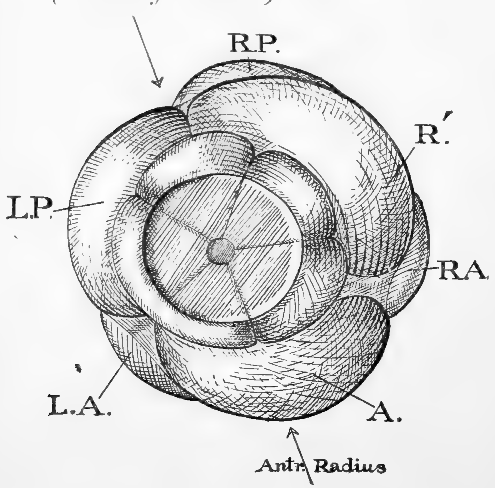
sole important difference between this calyx and that of *Pisocrinus*; in the latter, the second of the two plates exclusively united to a radial is the left anterior basal, which meets the middle of the base of the anterior radial. This is correctly indicated both by Bather and Wachsmuth & Springer, but, though true for the great majority of examples of *Pisocrinus*, the relation is not absolutely constant. Out of some hundreds of specimens of *Pisocrinus pillula* I have succeeded in finding three wherein the arrangement of the basal plates is precisely that which obtains in *Cicerocrinus*, while in a single example the basal plates are disposed in a manner almost precisely intermediate to that of *Pisocrinus* and *Cicerocrinus*. Thus, as shown in fig. 4, the right posterior is, as in both genera, interradial in position, and it never exhibits any tendency to deviate from this position; the left anterior and left posterior basals, however, are of approximately equal size, and meet in a longitudinal suture which corresponds to the suture between the anterior and left posterior

Fig. 3.—*Analytical representation of the calyx of* Cicerocrinus elegans. *(×2.)*



[The plates of the lowest series are basals, those of the two series of the next zone, radials; the remaining plates are brachials, except x, which is the anal plate. r=right; l=left; a=anterior; p=posterior; r'=radi-anal.]

Fig. 4.—Pisocrinus, *sp.: an exceptional specimen, in which the basal plates are symmetrically arranged, seen from the base. (× nearly 30 diam.)*



radials. From this intermediate form the normal *Pisocrinus*-calyx arises by an overgrowth towards the anterior of the left posterior basal, while the calyx of *Cicerocrinus* is produced by an overgrowth of the left anterior basal posteriorly. The radial plates of the calyx of *Cicerocrinus* correspond in their arrangement precisely with those of *Pisocrinus*, and differ only by their more elongate form, as is shown in the accompanying diagram (fig. 3), which is drawn to scale. The plate marked x by Mr. Bather is seen in a position precisely corresponding to that which it occupies in *Pisocrinus*.

It would thus appear that no essential difference distinguishes the calyces of *Cicerocrinus* and *Pisocrinus*; it is otherwise, however, when we pass to a consideration of the arms. These are five in number, well developed, and by no means excessively slender; in length they measure 37 mm., and in breadth 2·3 mm. near their origin, and 1·5 mm. near their termination. They are branched, pinnulate, with alternating syzygial ossicles.

The primary brachials are two in number, their breadth is 2·3 mm., and their length taken together is 4 mm. The secondary brachials number eighteen: the length of the series is 16 mm. and its breadth 2 mm. The tertiary brachials are as many as twenty-eight, the length of the series being 17 mm., and its breadth 1·5 mm.

The strong pinnules are plainly exposed on one side of the second and third divisions of some of the arms. A single pinnule arises from every fourth ossicle on one side, so that syzygial sutures may be inferred; occasionally, however, three ossicles intervene between two successive episyzygials. The articular surface for the pinnules is large, and the next ossicle which succeeds the episyzygial is deeply excavated to receive the basal joint of the pinnule. The ossicles of the pinnules are few in number, and longer than broad.

The structure of the arms agrees closely with that of these organs in *Ectenocrinus*, as represented diagrammatically by Mr. Bather,[1] though the pinnules of *Cicerocrinus* are represented by armlets in *Ectenocrinus*.

The association of branching pinnulate arms with a calyx possessing the characters of *Pisocrinus* renders necessary the erection of a new genus, for which I propose the name *Cicerocrinus*.[2] The form described is the only known example of the genus, and may be specifically designated *elegans*.

The calyx of *Cicerocrinus* is that of a Pisocrinid; the arms those of a Heterocrinid: but this conjunction of characters, though rendering necessary a fresh definition of the Pisocrinidæ, cannot be regarded as breaking down the distinction between this family and

[1] Ann. & Mag. Nat. Hist. ser. 6, vol. v (1890) pl. xv, fig. 7.
[2] *Cicer, ciceris*, a chick-pea.

the Heterocrinidæ, which are fistulate, while the Pisocrinidæ, so far as we know, are not.[1] We shall thus have:—

Family Pisocrinidæ, Ang. (emend.).

Calyx small, monocyclic, with five radial plates and a single radi-anal on the dorsal and five oral plates on the ventral surface. Arms five, either simple, uniserial, and destitute of pinnules, or dichotomous and pinnulate.

Genus 1. *Pisocrinus*, De Kon. With five basals, of which the left anterior meets the middle of the base of the anterior radial, and is exclusively united with it. Arms simple, not pinnulate. Silurian.

Genus 2. *Triacrinus*, Münst. With three basals. Arms simple, not pinnulate. Devonian and Carboniferous.

Genus 3. *Cicerocrinus*, gen. nov. Calyx with five basals, of which the left posterior meets the middle of the base of the left posterior radial, and is exclusively united with it.

The arms regularly dichotomize twice; the brachial ossicles are united by syzygy, and bear pinnules.

Type, *Cicerocrinus elegans*, sp. nov. Stem, calyx, and arms devoid of ornament and smooth; stem round; calyx elongated, conical; primary brachials two, secondary (in the only specimen known) eighteen, and tertiary twenty-eight in number. Silurian. Locality (?), probably Dudley.

EXPLANATION OF PLATE XVI.

[The figures are all taken from photographs of the specimens, made by Mr. J. A. Robinson.]

Fig. 1. *Brahmacrinus ponderosus*, gen. et sp. nov. The calyx nearly of the natural size (× 0·9), posterior view. The anal interradius almost faces the observer, but is turned slightly away to the left.

Fig. 2. The same: calyx seen from the right posterior side. × 0·9.

Fig. 3. *Cicerocrinus elegans*, gen. et sp. nov. Specimen seen from the anterior side. Nat. size.

Fig. 4. The same, giving a magnified view of the arms. × 2.

Discussion.

Mr. F. A. Bather congratulated the Author on his find of a new Monocyclic Inadunate crinoid from the Wenlock Limestone. A brief inspection of the fossil had not led him to doubt the Author's description, but he differed as to the systematic position of the genus for the following reasons:—Though the cup-structure was that of *Pisocrinus*, it must be remembered that the essentials of this structure were common to Heterocrinidæ, Calceocrinidæ, Pisocrinidæ,

[1] [Mr. Bather has called my attention to the fact that he has described a fistular character as existing in *Pisocrinus*. I have now consequently no hesitation in regarding *Cicerocrinus* as a link uniting the two families.]

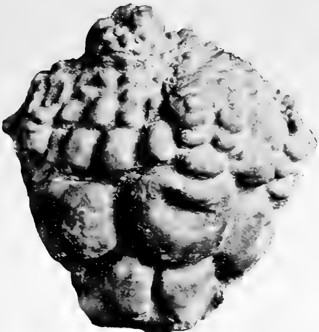


FIG. 1.

FIG. 3.

X 2

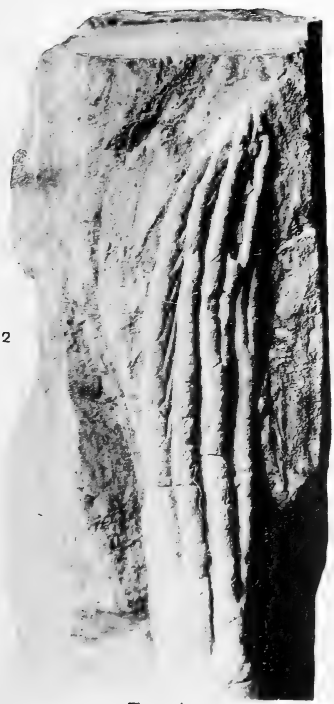


FIG. 4.

FIG. 2.

BRAHMACRINUS AND CICEROCRINUS.

Catillocrinidæ, and Haplocrinidæ, and that the particular Pisocrine arrangement was so natural a development from that of *Heterocrinu* that it would not, of itself, serve to distinguish the family Pisocrinidæ. On the other hand, the Pisocrinidæ, Catillocrinidæ, and Haplocrinidæ all possessed unbranched non-pinnulate arms, while the arms of all Heterocrinidæ and Calceocrinidæ were branched on a definite plan. The variation of arm-structure in Pisocrinidæ and Catillocrinidæ consisted solely in the gradual addition of unbranched arms, borne by small additional radials (pararadials). The variation of arm-structure in Heterocrinidæ and Calceocrinidæ consisted solely in a gradual advance, along definite lines, from isotomy to heterotomy, with the eventual production, in such a form as *Ectenocrinus*, of a bifurcated arm with ramuli along the sides of the rami, and with brachials forming syzygial pairs. Such a structure was absolutely removed from that of any Pisocrinid, but was, the speaker gathered, that of this new Silurian genus, which therefore fell into its natural position as the climax of the Heterocrinidæ.

Turning to the suggested new Carboniferous genus, Mr. Bather said that he felt unable to accept it. The proposed type-species had long been known; the attention of Wachsmuth & Springer had been specially drawn to it, and they had expressly retained it in *Platycrinus*, saying that 'a similar structure, in a less degree, is to be observed in a few American species.' The species was also connected with various British species, described and undescribed, showing no gap between it and ordinary *Platycrini*. It was hard to grasp what the Author intended as the diagnostic character. The presence of supplementary plates between the two main arm-branches was a feature of some interest, but the Author had rightly refrained from attaching importance to it. The abstract in their hands only mentioned 'the incorporation of the costal and distichal plates in the calyx,' a feature shared by many species of undoubted *Platycrinus* in both Europe and America. He understood, however, that the Author wished to take for his criterion the abutment of the costal (primibrach) on interbrachials. But this character could also be seen in such similar species as *Platycrinus punctatus*, *Pl. expansus*, and *Pl. tuberculatus*, not to mention such dissimilar species as *Pl. spinosus*, *Pl. mucronatus*, and *Pl. coronatus*. To speak of an 'annectant form uniting the Melocrinidæ and the Platycrinidæ' was to ignore time as well as structure.

The Author remarked that, as regards the new Silurian genus, the issue was very simple, until it became obscured amid the foliage of a genealogical tree. The calyx presented not merely a general but a precise resemblance to that of *Pisocrinus*, the arms could be compared with those of more than one genus of Heterocrinidæ. If chief stress be laid on the calyx, then the new genus is a Pisocrinid; if on the arms, it is a Heterocrinid. But the arms of crinoids, being organs of the highest physiological importance, are highly variable and less suited for broad distinctions in classification than the calyx. If this new genus could only be attached to Mr. Bather's 'tree' by the arms, it would be a misfortune for the 'tree.'

In the case of the other new genus described, not only were the costals and distichals fully incorporated in the calyx, but they were brought into immediate contact with the interradials; an arrangement not met with in *Platycrinus*, certainly not in *Pleurocrinus* (*Platycrinus*) *rugosus*, mentioned by Mr. Bather. The Author had in many cases used the terms proposed by Mr. Bather, but in others he had employed those in general use, which were also those of Wachsmuth & Springer. It mattered less what a thing might be called than that the same thing should always be known by the same name. In matters of nomenclature it was becoming increasingly difficult to keep abreast of the fleeting fashions of the time, and fixity in the use of terms was fast becoming a crying need in zoology.

16. Fossils *in the* Oxford University Museum.—III. *Ichnium Wattsii*, *a* Worm-track *from the* Slates *of* Bray Head: *with* Observations *on the* Genus *Oldhamia*. By Prof. W. J. Sollas, M.A., LL.D., D.Sc., F.R.S., V.P.G.S. (Read January 24th, 1900.)

[Plates XVII–XIX.]

The abundant literature which has been evoked by certain curious markings in the ancient rocks of Leinster since they were discovered by Oldham in 1844 (1)[1] is illustrative of the interest aroused by an unsolved problem. Its solution would appear to be still incomplete, and the present communication, while adding to our knowledge, at the same time adds to the facts to be explained. Of late years the subject has acquired additional importance, since the recognition of specifically identical markings in similar rocks of other parts of Europe (12, 13, 14, 21) and America (23) has led some geologists to regard them as guides to the 'identification of strata.' Without expressing any opinion as to their value for this purpose, it may yet be noticed as a very remarkable circumstance that hitherto *Oldhamia* has not been recorded from younger rocks than the Lower Palæozoic; according to most writers, indeed, it is confined to the Cambrian System. Thus in the Ardennes *Oldhamia antiqua* is found associated with *Nereites cambrensis* in the greyish-green phyllades of Fumay; and in the Devillo-Revinian of Stavelot *O. radiata* occurs together with an *Agnostus* and *Arenicolites didymus*. In Brabant *O. radiata* is met with in the middle member of the series of phyllades and quartzites which are there supposed to represent the Cambrian. At one time De Lapparent[2] cited *Oldhamia* as present in Ordovician strata; his words are as follows:—'À la base [of the Silurian System] s'observent à Boutoury les couches à *Bellerophon Œhlerti* et à *Didymograptus* dont les assises inférieures offrent le mélange d'*Agnostus* et *Oldhamia* avec *Megalaspis*, *Calymene*, *Illænus* (c'est l'horizon d'Arenig).' In the latest edition of the 'Traité,' the statement is repeated; but the horizon is given as that of *Ceratopyge* (p. 805).

Barrois (23) has described a species of *Oldhamia* from Palæozoic schists in the Pyrenees; the locality is given as the ravine of Montmédan-Maju, near Jurvielle (Haute Garonne). The genus is also probably represented in the Cambrian rocks of Norway; Kjerulf's statements on this point are, however, very guarded, and unaccompanied either by figures or descriptions. Thus he speaks (12) of 'impressions which strongly recall those of *Oldhamia*,' and of 'traces of sand-worms and *Oldhamia*' as occurring in association with the 'Blue Quartz.'

[1] The numbers in parentheses throughout this paper refer to the Bibliography on p. 284.

[2] 'Traité de Géologie' vol. i (1893) p. 780.

The rocks which have furnished *Oldhamia* in Ireland have always been regarded as belonging either to the Cambrian or to some still more ancient system; but the observations of Mr. MacHenry, according to whom *Oldhamia* occurs in Wexford in intimate association with Ordovician fossils, have suggested doubts on this point.

In America, according to Barrois, a form of *Oldhamia* is said to occur plentifully in the Potsdam Sandstone (Upper Cambrian) of Wisconsin.

No instance is recorded of *Oldhamia* from strata of later age than the Ordovician, and I have never myself met with any markings comparable to *Oldhamia* in rocks younger than those of Bray Head; this comparatively narrow restriction in time, notwithstanding a wide distribution in space, is a very noticeable fact, and should be carefully borne in mind in discussions as to the origin of *Oldhamia*.

The genus *Oldhamia* was defined by E. Forbes (2), who recognized two species, *O. radiata* and *O. antiqua*. Later J. R. Kinahan (3) added a third species, which has not been generally accepted; Baily (6) speaks of it as a mere variety of *O. radiata*. Göppert (5) regarded the distinction between the two species of Forbes as of generic value, and, while retaining *O. radiata* as the designation of one, renamed the other *Murchisonites Forbesi*. In this procedure he has not been followed by other investigators. The species *O. Hovelaquei*, described by Barrois (23), differs in several respects from either of those found at Bray. It is larger, and consists of a definite number of processes (twelve) having a flabellate arrangement, inserted independently at the same part of a stem, which is slightly swollen to receive them; this stem proceeds from another, which is similar but slightly longer; a whorl of appendages, such as occurs in *O. antiqua* at the point of branching of the stem, is not present in *O. Hovelaquei*. The appendages are semicylindrical, simple, smooth, and obtuse at the end, 20 mm. in length and 1 mm. in breadth. The stem from which they proceed is 20 mm. in length, and only slightly thicker than the appendages.

A specimen of the new fossil, *Ichnium Wattsii*, to be presently described, is classed with *O. radiata* in the collection of the Geological Survey of Ireland.

The organic nature of *Oldhamia* was scarcely a matter for doubt in the minds of the earlier writers; it was described by its discoverer (1) as 'small zoophytic markings, which do not appear to be referable to known genera.' Great diversity of opinion, however, marks the attempts to assign to it a definite place in the organic world; thus Forbes (2), while noticing its resemblance to Sertularian zoophytes or polyzoa, concludes by allying it with the Tunicata; J. R. Kinahan (3), to whom we are indebted for the fullest and most accurate description of *Oldhamia*, confidently

placed it with the Hydrozoa, as also did Baily (4, 9, 11); while Göppert (5) was inclined to regard it as a plant, comparing *O. radiata* with *Sirocoleum* of Cayenne or *Tolypothrix coactilis* of Jutland, and *O.* (*Murchisonites*) *antiqua* with *Liagora lamellosa*, a species of Phycaceæ. The majority of palæontologists subsequent to Göppert seem to have accepted his views as to its vegetable nature; thus Salter (7) concluded that it was a calcareous alga, 'can scarcely be otherwise' he remarks, and later (10) he cites Dr. Busk and the Rev. J. M. Berkeley as being of the same opinion, which was also shared by Schimper (8). Salter quotes Berkeley as comparing *Oldhamia* with the Siphonacean alga *Acetabularia*. Barrois (23) associates it with *Chondrites*, and as regards the species *O. Hovelaquei* in particular he remarks that the regular ramification of the stem and the flabellate arrangement of the appendages forbid a comparison with the tracks left by an animal.

The first to question seriously the organic nature of *Oldhamia* appears to have been Rœmer (13), who regarded it as a mere wrinkling of the rock due to pressure; his words are 'durch Druck oder Zusammenziehung hervorgebrachte Rünzelung oder Fältelung des Thonschiefers.' This view was adopted by Nathorst (14), and later advocated on independent evidence by the present author (19, 20), who was not aware that he had been anticipated by Rœmer. Dr. Joly, who was at first disposed to attribute *Oldhamia* to crystalline action (18), was afterwards led to change his views, and reverted to the belief in its organic nature; the present author (24) likewise abandoned his first position, and compared *Oldhamia radiata* to 'the radiate branched markings which may sometimes be seen on muddy flats, extending from the mouth of the tubes of burrowing worms.' Prof. Bonney (22) had previously urged several weighty objections against the theory of the inorganic origin of *Oldhamia* (see p. 276).

On commencing the study of *Oldhamia* I approached the subject under the impression, which prevailed at the time, that it was the genuine remains of some organism, but since it did not present such characters as might be expected in a hydrozoon or polyzoon, I fancied that it might possibly be some form of calcareous alga. A well-preserved specimen in the Geological Museum of Trinity College, Dublin, seemed likely to throw some light on the question, since it presented, in addition to the usual characters, indications of structure traversing the substance of the matrix. An examination of thin slices under the microscope seemed to show, however, that these appearances were fallacious; a structure was certainly present, but not of an organic nature, nothing more indeed than a wrinkling of the laminæ of the rock. An examination of numerous other specimens led to similar results. It thus seemed definitely proved, that whatever else *Oldhamia* might be, it certainly was not the remains, or the pseudomorph of the remains of an organism, but merely a marking in the slate. True, such a marking might conceivably be of organic origin, but an explanation which would

refer it to mechanical deformation as the result of pressure was the one which at that time commended itself to my mind. This, however, was not without its difficulties, since the radiate disposition of the wrinkles, which express themselves as *Oldhamia*, were not likely to have been produced by general earth-pressure; and had to be accounted for by local action, which was not suggested by the general structure of the rock. Prof. Bonney, perceiving the force of this difficulty, offered several just criticisms of the conclusion to which I had been led. He pointed out that the ridges of *Oldhamia* are far more definite than the puckerings in an ordinary wrinkled phyllite, and that, while puckered phyllites are numerous, *Oldhamia* is very rare, and does not occur in ordinary examples of such a rock. Reference was also made to the fact that the wrinkles of *Oldhamia* sometimes cross each other, so as to produce a reticulate appearance, which would hardly be the case were they the result of simple puckering.

Several years later I had the advantage of examining, under the direction of my friend Prof. Watts, the fine collection of *Oldhamia* made by the officers of the Geological Survey, and preserved in the Museum of Science & Art, Dublin; among these was one in particular, labelled *Oldhamia radiata*, which could not possibly be accounted for by rock-folding, and which recalled certain appearances that I had remarked many years previously on the muddy flats of the Bristol Channel, in the neighbourhood of Portishead. Fortunately I had made a rough sketch of these at the time, and on referring to this I found that it fully supported the comparison. The recent markings were certainly made by an organism, which I thought might be some kind of worm. On requesting my friend Prof. Lloyd Morgan to make a search for the animal, he very kindly consented, and sent me a gathering, not of a worm, but of a small crustacean. Later I had an opportunity of visiting Portishead, and watching this crustacean in great numbers actively at work, so that I was able to trace every step in the formation of its tracks. The little creature lives for the most part completely immersed in the mud, but at intervals it projects its anterior extremity above the surface, and with its long claw snips off a minute strip of the superficial layer, which is doubtless rich in organisms; it then descends into the mud, and on re-appearing takes another snippet near to, but not quite touching, the side of the first; this process is repeated till a wheel of gashes round the central area is the result. The excisions are at first quite sharply defined, but very soon, since they are inclined towards the centre, water begins to slowly drain along them; this leads to their extension outward in a centrifugal growth, which is accompanied by bifurcation, as tiny tributaries contribute to the main streams.

Suggestively similar as these markings are to some forms of *Oldhamia*, it by no means follows that the latter were produced by a crustacean; were this the case, some other traces of the existence of the organism besides mere superficial markings might be naturally expected to occur in association with *Oldhamia*, while nothing is

more marked than the complete absence of ordinary 'fossils' from the slates of Bray Head.

It still remains possible, however, that some other organism, possibly an annelid, which might easily disappear without leaving other traces of its existence, was responsible for these markings; and having had occasion recently to consult a memoir by Nathorst (14) on the tracks made by various organisms on the sea-floor, my attention was arrested by two figures representing the tracks of a worm and closely resembling the specimen shown to me by Prof. Watts in the collection of the Irish Geological Survey. This specimen I believe to be an example of the new species *Ichnium Wattsii*, the type of which is represented in Pl. XVII, fig. 1, reproduced from a photograph of a specimen found by my friend and former pupil, Dr. N. Alcock, while we were examining together the rocks at Bray Head. It occurs on the surface of a fine-grained red shale or phyllite: one half, showing the impression in intaglio, is preserved in the Geological Museum of Trinity College, Dublin; the other, in which it is in relief, is in the University Museum, Oxford. On comparing *Ichnium Wattsii* with the figure (Pl. XVII, fig. 4) given by Nathorst of the impression made by a recent worm, *Glycera alba* or *Gonidia maculata*, both of which live on muddy bottoms at a depth of 15 feet, a close resemblance will be recognized. The radiating depressions are similarly related to the central area in each; in neither case do they unite into a single central depression, but plunge downwards independently; in both they are fairly well defined; and finally, in both they cross each other and lose themselves at the periphery in a manner strictly comparable. Thus *Ichnium Wattsii* does not present a single feature by which it can be distinguished from the track of a recent worm.

The question next arises as to the relation of *Ichnium* to *Oldhamia*. On first writing this paper I assigned the new species to *Oldhamia*, and though suggesting that it might represent a new genus, I refrained from expressing this in our nomenclature, out of a desire not to unnecessarily add to its burden. But in this parsimony of new terms there was involved unconsciously an economy of logic; for if *Ichnium* be *Oldhamia*, then *cadit quæstio*, and *Oldhamia* is the trace of a worm, but this is a conclusion that cannot be so summarily attained. It becomes necessary to make a further investigation of *Oldhamia*, and this reveals so many important points of difference between that genus and *Ichnium* that the question of the origin of *Oldhamia* must be discussed on its own merits.

The form and character of both species of *Oldhamia* are far more definite than is usually supposed, and it is important that they should be exactly studied, especially as this may lead to their successful use as zone-fossils. Before proceeding to this task, it may be convenient to dispose of the arguments of those who have attributed an inorganic origin to *Oldhamia*. In this connexion it is

interesting to observe that the resemblance of *O. radiata* to the tracks of worms had not escaped the notice of Nathorst, who, however, only discusses the similarity to reject it as a valid explanation. The first objection of this author, that the markings of *Oldhamia* are too vaguely defined for the track of a worm, will scarcely be admitted by those who have had the advantage of examining fairly good specimens. Prof. Nathorst has apparently seen only those contained in the collections of Munich and Lund, and that these are possibly not very good examples is suggested by the remark that the ordinary illustrations of *Oldhamia* are somewhat imaginative. This is a reproach which the careful drawings of a number of distinguished palæontologists—Salter, Kinahan, and Baily—scarcely deserve; for my part I am inclined to think that an impartial student who should compare the original specimens with the corresponding figures would be led to pronounce the latter as unusually good and remarkably true to nature. One of Salter's representations of *O. antiqua* is perhaps slightly diagrammatic, but not 'fort idéalisée,' while Rœmer's diagram of *O. radiata*, so far from being, as Nathorst remarks, 'plus conforme à la nature,' is a mere travesty of the actual marking. Baily's later figures are not quite so exact as his earlier ones, owing to a tendency to project into them hydrozoonal characters, which expresses itself in a somewhat jagged outline given to the margin of one side of the rays. The remaining objections of Nathorst are cited from Rœmer (13) as follows:—The parts of the marking are disposed in a completely irregular manner; there is no definite centre towards which the rays converge; the markings are not connected with any difference in chemical composition of the rock-matrix; and finally, *Oldhamia* is not accompanied by any other organic remains. Nathorst adds that certain specimens of the 'marlekor' of Lapland present in the interior a structure resembling *Oldhamia*, and suggestive of a possible 'mechanico-chemical' origin, but he does not give either descriptions or figures of this structure.

While some of the arguments advanced by Rœmer may be calculated to dispel a belief in *Oldhamia* as representing the actual remains of an organism, they are by no means opposed to the view that it has been formed by the movements of some burrowing worm. The tracks of recent worms figured by Nathorst are not more regular than *Oldhamia*-markings; they are not characterized by a more definite centre, nor are they more sharply defined, probably rather less. They are not associated with chemical differences of the mud, nor need they be accompanied by obvious evidence of the existence of contemporary organisms. Finally, it cannot be conceded that *Oldhamia* is destitute of companions; ordinary worm-tracks, such as are made by the crawling of animals over a muddy surface, are more commonly found along with *Oldhamia* than not. *Histioderma hibernicum*, almost certainly a worm-burrow, is a well-known associate, and there are others: such as *Pucksia Mac-henryi* (25), which, though of doubtful systematic position, is indubitably of organic origin. After this discussion, in which the

most weighty arguments against the organic origin of *Oldhamia* have been considered, and, it is hoped, disposed of, we may proceed to a description of the two Irish species of the genus, the result of a prolonged and careful investigation under the microscope.

Oldhamia radiata. (Pls. XVII–XIX.)

This is a radiate system of branching grooves, proceeding from a central area (Pl. XVII, fig. 2). The central area may be depressed below the general level of the surface of the phyllite, or raised tent-like above it, more frequently the latter; in some cases it is occupied by the origin of the branches, in others marked by more or less hemispherical pits; occasionally it is a plain surface, and sometimes, but not always, defined by a faintly-impressed closed curve. The radiate grooves are very sharply defined, variable in number, narrow, about 0·4 mm. in breadth, repeatedly branching till they terminate in club-shaped processes. These processes are narrow at the origin, but gradually grow broader till they attain the breadth of the main grooves, and terminate in a rounded extremity; their length, though variable, is as a rule about 3 mm. Not infrequently the terminal processes fail to show continuity with the rest of the impression: this is, in some cases, the result of the excessive attenuation of the proximal extremity; in others the discontinuity is absolute, and no connexion between the process and the chief grooves can be discovered. Usually, but not always, the club-shaped processes are remarkably straight; frequently they are constricted at more or less regular intervals, so as to present the appearance of a row of hemispherical pits. These pits are presumably the 'cells' of J. R. Kinahan's description, which are stated by that author to be biserial in arrangement. This I have not yet observed; in my specimens they form but a single series. In some specimens long isolated tenuous furrows, 25 mm. in length, 0·3 mm. in breadth, extend for a considerable distance beyond the general outline of the marking, and may be occasionally seen to terminate in a club-shaped extremity, after having given off on one side one or two other club-shaped processes (Pl. XIX, fig. 13): there is no discoverable constriction at the origin of these processes. These isolated sprays of the main impression are particularly instructive, since as a rule the crowding of the branches renders it difficult to ascertain their true characters. Occasionally disconnected, simple, straight, semicylindrical grooves, and hemispherical pits lie scattered on the surface of the phyllite in the vicinity of a radiate system. The phyllites in which *Oldhamia* occurs are generally devoid of all traces of transverse cleavage; but the effects of tangential pressure are shown in many instances by a compression of those grooves of a system, which extend at right angles to what must have been its direction, and I was thus led to suspect that the constrictions which give a beaded appearance to the club-shaped processes might also have resulted from its action. This, however, is plainly not the

case; the beaded appearance is most obviously displayed by those specimens which exhibit no effects of pressure.

The grooves of *O. radiata* sink below the smooth even surface of the phyllite, without any corresponding ridges to bound them at the sides; only in the case of one or two isolated linear grooves have I seen a faint mound running parallel along each side (Pl. XIX, fig. 12).

Of the two species of *Oldhamia*, *O. radiata* most closely resembles *Ichnium Wattsii*, but even this is distinguished by a multitude of important details, its grooves are far more sharply defined, branched incomparably more frequently, and they terminate in club-shaped processes, which find no parallel in *Ichnium*.

Oldhamia antiqua. (Pls. XVII–XIX.)

It has been shown by Prof. Joly that while *O. radiata* consists of a system of grooves, *O. antiqua*, on the other hand, occurs as a system of ridges. The assertion has been doubted, but there can be no question as to its general truth; Prof. Joly's specimens, which he has kindly lent me for examination, fully bear out his statements. The rule, however, is not, I think, absolute, for in one example of *O. antiqua*, displaying most of the structure in relief, four of the radiate processes are in depression. I owe to the kindness of Prof. Joly the loan of the beautiful example of *O. antiqua*, which is represented by the accompanying photograph (Pl. XVII, fig. 3). A long broad ridge or stem, 12 mm. in length by 1 mm. in breadth, resembling the trail of a worm, though in relief, expands as it gives origin to the well-known fan-shaped system of appendages of this species. The appendages do not arise immediately from the swollen extremity of the stem, but from an ill-defined oval area, which is far better marked in many specimens (Pl. XIX, fig. 11) than in this; its surface is, as a rule, remarkably smooth and even; the appendages arise singly and abruptly just within its outer margin.

The appendages may be simple or branch once or twice; the simple or final branches are more or less club-shaped and beaded, after the same fashion as the grooves of *O. radiata*, except that in this case the beading is sometimes biserial. They are straight or curved, rarely undulating, and have a suggestive appearance of rigidity, such as may also be remarked in the terminal processes of *O. radiata*. In all published descriptions of *O. antiqua* the stem is said to be continued onwards and to geniculate, a fan-like system originating at each geniculation. This may be so, but I have never been able to convince myself that such is the fact: in all cases that I have examined the second fan appears to arise at the termination of two of the appendages of the first, the third from two of the second, and so on. It is possible, however, that the ridges, which I regard as representing two appendages, are the sides of a stem crushed in along the middle; but I can discover no feature by which they are to be distinguished from ordinary appendages.

Associated with *O. antiqua* are certain markings which do not seem to have been yet described (Pl. XVIII, fig. 9): these are oval areas, with well-defined slightly raised margins, depressed within like a very obtuse inverted cone, the apex of which is truncated by a circular area of a different texture and colour; the whole is the upper end of a corresponding structure that extends vertically downward through the rock (Pl. XVIII, fig. 10); the central circular area or cylinder is suggestively similar to a worm-tube, and the conical depression with its annular cylinder to the mucilage-cemented wall of such a tube. Whether this structure stands in any direct connexion with *Oldhamia antiqua* is difficult to determine; the frequent absence of any *Oldhamia*-appendages around it would suggest a negative answer, but in one case such appendages are to be seen radiating over the sides of the conical depression and having its apex as their centre; this, however, is a solitary instance, and may be merely accidental.

Before proceeding further, it may be at once remarked that, while some of the characters described may be consistent with the theory that *Oldhamia* is a worm-track, there are several others that are difficult to reconcile with such an explanation. The sharply-defined club-shaped processes of *O. radiata* are not like any worm-marking, and the relief of the form of *O. antiqua* is inconsistent with the nature of a worm-track; I have endeavoured to meet this objection by suggesting that *O. antiqua* represents the excrementitious castings of a worm. It is singular, if this be so, that the two species, *O. antiqua* and *O. radiata*, should be so rarely found together; some localities, such as Carrick Mountain (Wexford), are said to have afforded abundant specimens of *O. antiqua*, but none of *O. radiata*, and it is a fact familiar to collectors that, though both species occur at Bray Head, they are seldom found in the same bed. We may now pass to the consideration of further features, which are, if anything, still more strongly opposed to the vermiform nature of *Oldhamia*.

The rocks in which *Oldhamia* occurs at Bray are exceedingly fine-grained, highly-laminated, hardened shales, sometimes red, sometimes green. They consist largely, perhaps chiefly, of sericite, with abundant chlorite, granules of ferric hydrate, and sometimes minute grains of quartz. The smooth surfaces of the laminæ were admirably adapted to receive and retain the finest impressions, so that the preservation of a trace like *Ichnium Wattsii* need not cause the least surprise. It is, however, remarkable that no change of colour occurs in the red beds in the vicinity of *Oldhamia*, but obvious worm-markings are similarly destitute of green borders. Notwithstanding the fineness of grain, there is no reason to suppose that the rocks were very slowly deposited, rather the contrary; the sandier beds are often extremely false-bedded, and occasional beds of coarse grauwacke are intercalated, as well as numerous massive beds of quartzite.

In thin slices of the rock devoid of *Oldhamia*, the laminæ present

themselves as straight parallel lines or bands, but when *Oldhamia* is present the laminæ are curved conformably with the grooves or ridges of the impressions (Pl. XIX, fig. 15). In some cases there is a maximum inflexion confined to a single lamina not more than 0·1 mm. in thickness, and the curvature rapidly passes away above and below, so that no signs of it remain at a distance of about 1 mm.; in other cases the maximum deflection is uniformly repeated by successive layers through a distance of several millimetres. This fact is very difficult to explain on any hypothesis, most of all on that which invokes the agency of worms. It may be objected that the successive conformable wrinkles of any one *Oldhamia*-system represent a succession of single systems. But if this were so, two tangential sections at an interval of some millimetres apart should not show an identical 'pattern' (Pl. XVIII, figs. 6 & 8); no burrowing animal would make successive grooves vertically over one another of the same character and in the same direction. Nor on the other hypothesis to be presently approached, that *Oldhamia* may be the trace of a plant, would whorls of appendages be successively produced which resembled one another in every particular, both of size, direction, and form. There would appear to remain one, and only one, explanation: the inflection of one lamina alone is original, that of the others is secondary and the result of pressure. But the conditions requisite to bring about this result involve the existence for a time of some resisting substance in the place now indicated by *Oldhamia*.

We might then represent matters to ourselves as follows:—Taking first the case of *O. radiata*, let us suppose it to represent, as Berkeley acutely suggested, the branches of some calcareous Siphonaceous alga; its lower surface will form an impression on the surface of the mud on which it must be supposed to rest; if deposition be slow, it will decay before many millimetres of sediment have covered it, and a single groove will be all that remains to mark its place; but if deposition on the contrary be rapid, it may be buried beneath a considerable thickness before it disappears, and the vacant place that it leaves behind will be filled by a downward sinking of the superincumbent laminæ. It has for a long time seemed to me that a fairly average rate of deposition would be about 300 mm. per century, and if we assume that the *Oldhamia*-bearing rocks sometimes accumulated at the rate of 500 mm., then two years would be required for the deposition of 10 mm. If *Oldhamia* were so long in passing away, the overlying laminæ might adjust themselves to the resulting cavity, so as to repeat the form of its floor through a thickness of 3 mm.

Turning next to *O. antiqua*, we should have to assume that its upper surface was for some reason more resistant than the lower, and that as it yielded from below the underlying sediments rose up to take its place; this species would thus be represented by a 'creep' of the laminæ, the other by a 'sit.' That a very slight difference in conditions determined whether a sit or a creep should take place is indicated by the fact that sometimes one part of *O. antiqua* exists in relief and another in depression. Although

Oldhamia is usually represented in sections by simple grooves, cases occasionally are found in which the sides of the groove are raised into overfolded lips, which sometimes meet and enclose an elliptical space.

A singular structure, which I at first explained as indicating the presence of the excreta of worms, may next be described (Pl. XIX, figs. 14 & 16). In the midst of the thin parallel laminæ of the rock, certain markings arrest the attention by their definite circular outline; they vary considerably in size, but most of them are between 0·2 to 0·5 mm. in diameter; on closer examination many are found with an elliptical outline, and some bounded by an irregular closed curve. Not infrequently a concentric arrangement of lighter and darker particles may be observed within the outer boundary, and occasionally radiating lines which proceed from the centre outwards. A large circle often includes a number of smaller circles within it, and adjacent circles may intersect each other. These appearances are due to a definite arrangement of the minute particles which constitute the rock. Sometimes the markings are dark on a light ground: in such cases short lines and dots of ferric hydrate, and minute granules of opaque yellowish-white material (possibly decomposed felspar, possibly leucoxene), most obviously determine the outline. In other cases the markings are light on a dark ground: these are due to a circular arrangement of minute scales of mica and chlorite; in one or two instances a radiate arrangement of sericite-scales has been observed. On first examination these remarkable forms seem to be scattered haphazard through the rock, but in good specimens careful observation shows that they tend to run in lines, sometimes parallel to the lamination, but more often across it. Sometimes a concentric system of circles fills an *Oldhamia*-groove, sometimes such a system lies immediately below, but connected with the groove by a narrow neck; or again several rows of circles branch out rootlike from the floor of a groove, and not unusually such rows are bounded on each side by fine parallel opaque lines, when the structure recalls the appearance of a racemose gland. These systems of curves traverse the laminæ without disturbing their course, and are as circular in transverse as in horizontal sections. Further, although best displayed in the *Oldhamia*-beds they are to be met with in a great variety of fine-grained rocks. Some difficulty may be experienced in first recognizing them, which may account for their having hitherto escaped notice, but once pointed out they become sufficiently obvious. They may be seen both by transmitted and reflected light, and are easily photographed.

It is not unnatural to regard the 'balled' structure suggested by these markings as indicating the excreta of worms, particularly as we are assured that the majority of deep-sea animals live by eating the mud at the bottom, and that every particle of mud of the sea-floor has at some time passed through the intestine of a worm. While recognizing that a possible explanation may lie in this direction, I am more disposed to regard the balled structure

as wholly secondary. There may be isolated instances in which the structure is accompanied by a difference in mineral composition, distinguishing it from the rest of the lamina, and these may be original; but in the great majority this is not the case; and I would venture to suggest that the structure, as typically displayed, is the result of concretion, if we may use a term which is so often lamentably abused. I am the more inclined to this explanation since I have been able to produce a closely similar structure by artificial means. If a fragment of *Oldhamia*-slate be rubbed down on a hone, and the fine mud thus produced be allowed to stand for a few minutes, a concentric arrangement of fine particles, very similar to that already described, may be observed; by pouring the thin mud or muddy water on to a glass-slide the structure develops under conditions which allow it to be studied by transmitted light under the microscope, and it may then be photographed. The cause of this phenomenon is not clear to me, but it is possibly connected with cohesion; whatever the cause, the concentric arrangement in the *Oldhamia*-beds appears to be a similar effect, while the associated linear streaks of opaque granules may have resulted from the slow movements of water as it escaped from the gradually consolidating sediment of which the beds consist.

The nature of *Oldhamia* cannot yet be regarded as definitely ascertained. That it is of organic origin seems to me scarcely to admit of doubt; whether the organism were animal or plant, and in what manner it imprinted its traces on the rocks are questions that still await a definite solution.

Ichnium Wattsii, gen. et sp. nov. (Pl. XVII, fig. 1.)

A radiate system of continuous, undulating, bifurcating furrows, of a uniform width of 0·5 to 0·6 mm., of a maximum length of 28 mm., with rounded terminations. Central area occupied by cylindrical elevations, which plunge downwards into the matrix. Occurrence: indurated red shale, ½ mile south of Bray Head.

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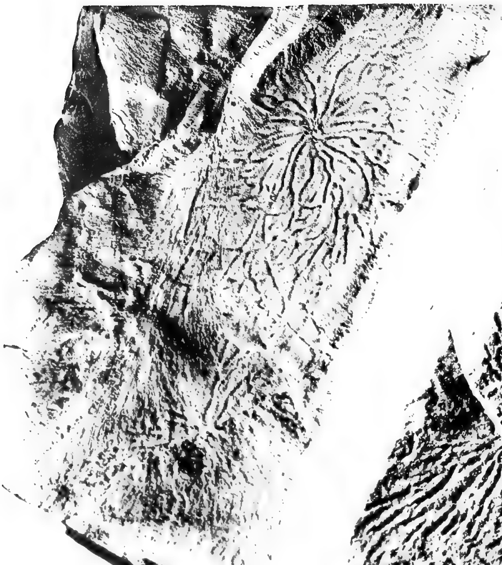

x 0.9

Fig. 1.

x 2

Fig. 2.

x 2 Fig. 3.

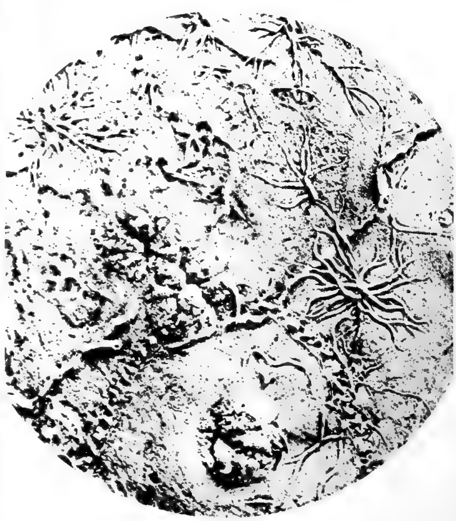

Fig. 4.

Ichnium and Oldhamia.

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EXPLANATION OF PLATES XVII–XIX.

PLATE XVII.

[For the photographs on this Plate I am indebted to Mr. J. A. Robinson.]

Fig. 1. *Ichnium Wattsii*, gen. et sp. nov. From a photograph of a specimen in the Oxford University Museum. × 0·9.

2. *Oldhamia radiata*, Forbes. From a photograph of a specimen in the Oxford University Museum. × 2.

The club-shaped terminations of the radial grooves are well displayed in places, particularly about an imaginary line joining the centres of the two individuals on the slab. A joint crosses the slab obliquely, cutting through the lower of the two individuals; on the lower left-hand side of the joint a layer of the rock has been flaked off, so that the exposed surface here lies 4 mm. below the general level, and the rays seen upon it are the outward continuation of the structure, which to the right and above lies concealed 4 mm. below the markings actually represented. The rays of the lower surface are also the downward continuation of the marking which once lay 4 mm. immediately above them: notwithstanding this, they are seen to continue the direction of the rays on the preserved upper surface, and are scarcely inferior to them in sharpness of impression. (Oblique fractures sometimes reveal the extension downward of one system of grooves through a thickness of 1 cm.)

3. *Oldhamia antiqua*, Forbes. From a photograph of a specimen in the possession of Prof. J. Joly, D.Sc., F.R.S. × 2.

4. Tracks of a living worm. (After Nathorst.)

Plate XVIII.

[The figures of this Plate are reproduced from photographs of actual specimens, and are uniformly magnified 4·4 diameters.]

Fig. 5. Central region of a system of *Oldhamia radiata.* Many of the radial grooves are constricted at intervals, so as to form a series of pits.

6. Part of a system of *O. antiqua,* exposed on the surface of a slab of indurated shale, for comparison with fig. 8.

7. Several of the rays of *O. antiqua,* showing a beaded appearance. This will be most readily seen by viewing the figure from the left-hand side.

8. Part of the same system of *O. antiqua* as that shown in fig. 6, but exposed on a polished surface parallel to that of fig. 6, lying 3 mm. below it. To compare the two figures, fig. 8 should be viewed in a mirror, and the obtuse angle in the outline of the upper right-hand side made to correspond with the similar angle on the lower left-hand side of fig. 6.

9. View *en face* of one of the oval depressions on the surface of the shale, often associated with *Oldhamia.* Owing to its conical form, it cannot be brought uniformly into focus.

10. The structure, which descends through the rock from such a depression as that shown in the previous figure, exposed in horizontal section, 3 mm. below the level of the surface on which the depression occurs.

Plate XIX.

[The figures of this Plate are reproduced from photographs of actual specimens.]

Fig. 11. Central area of a fan of *Oldhamia antiqua,* showing the smooth oval area, from which the rays originate. × 4·4.

12. Isolated rays of *Oldhamia*; the two upper parallel ridges are bordered by faint surrounding mounds. × 4·4.

13. An isolated spray of *O. radiata,* showing three club-shaped terminal processes. × 4·4.

14. Part of a vertical section through a slab of rock containing *Oldhamia.* A little below the centre, and slightly to the left, a single groove is clearly displayed; it is a section across a single *Oldhamia*-ray. An almost perfect circle (black in the photograph) rests in the groove, and a linear disturbance of the laminæ of the rock is seen on each side outside the groove running transversely. Indications of a circular arrangement of particles are common throughout the general substance of the rock. × 22.

15. Vertical section through *Oldhamia*-bearing rock. × 4·4.

16. Part of a similar section, to show scattered concentric systems of circles. × 22.

Discussion.

Mr. E. T. Newton and Prof. W. W. Watts spoke.

The Author thanked the Fellows for the favourable reception which they had given to this communication. The subject was not yet exhausted, and it was possible that with further investigation some of the points that still appeared obscure would be elucidated.

[*Postscript.*—The crustacean mentioned on p. 276 is an amphipod, and it has been kindly determined for me by Dr. Goodrich as *Corophium longicorne,* Lat.—W. J. S., April 26th, 1900.]

X 4.4

FIG. 5.

X 4.4

FIG. 6.

X 4.4

FIG. 7.

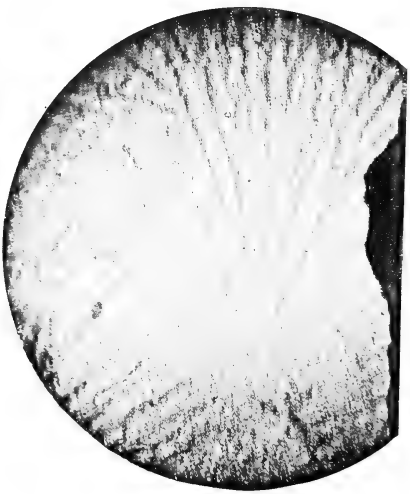
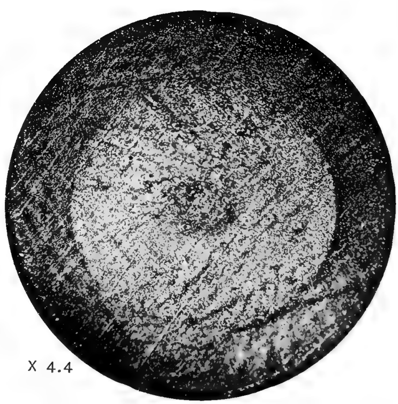


FIG. 8.

X 4.4

FIG. 9.



X 4.4

FIG. 10.

OLDHAMIA.

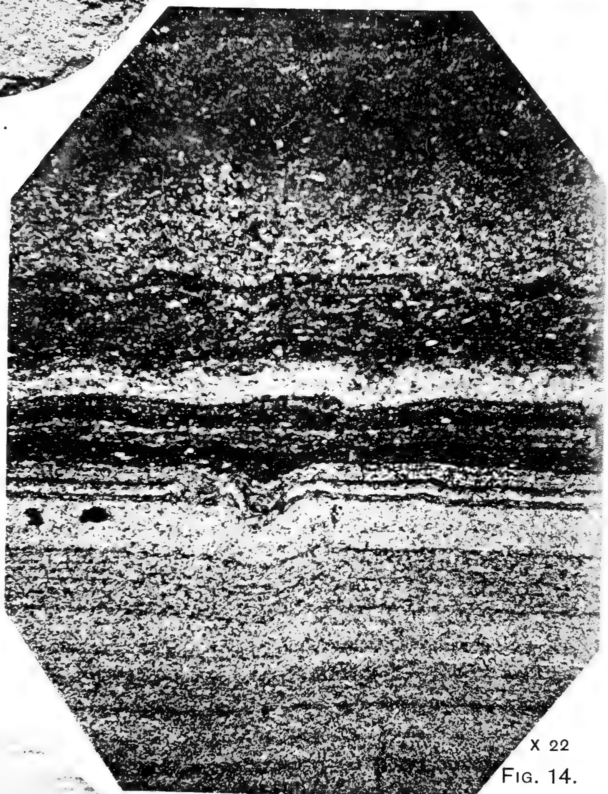
x 4.4

Fig. 11.

Fig. 12. x 4.4

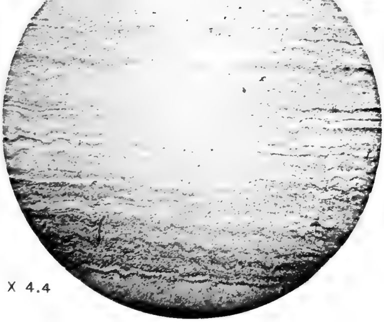
x 4.4

Fig. 13.



x 22

Fig. 14.



x 4.4

Fig. 15.

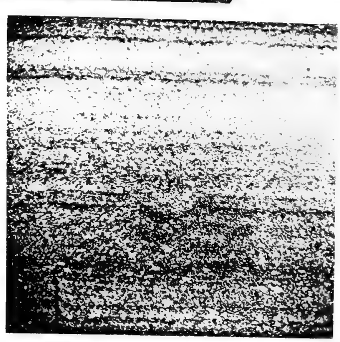


Fig. 16. x 22

Oldhamia.

17. *The* Bunter Pebble-beds *of the* Midlands *and the* Source *of their* Materials. By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S. (Read February 21st, 1900.)

[Plate XX.]

Contents.

I. Introductory.

Until the summer of 1895 I spent at least a month in every year in the immediate neighbourhood of the northern end of Cannock Chase. In 1880 I published[1] a short note on the pebbles in the Bunter Conglomerate, so largely developed on that moorland. A second appeared in 1883,[2] and the subject was mentioned in my address to Section C at the meeting of the British Association in Birmingham in 1886.[3] In 1890[4] I replied briefly to certain criticisms on the hypothesis which I had adopted in regard to the origin and history of these pebbles. Besides this, I published in 1888[5] some observations on the action of rivers in forming pebbles, the results of a journey planned with a view of obtaining the necessary facts,[6] and in 1895[7] a note on the Budleigh Salterton pebbles which I had examined for comparative purposes. Since that year, when my close connexion with Staffordshire was broken, the pressure of other work has kept me from putting together information acquired after 1886, drawing up a summary of the whole evidence, and pointing out its bearing on the hypotheses which have been advanced as to the origin of the pebbles.

Throughout my work, though it was rather desultory, I have gathered facts for myself, and so shall not attempt to burden these pages with an elaborate list of the 'literature of the subject.' That prior to 1869 is enumerated in the memoir of the Geological Survey on the Coal Measures, Permian, and Trias of the Midland Counties (by Prof. Hull), which is full of valuable facts; my own papers contain references to the few which I have had to notice, and one or two others will be mentioned in the course of this communication. I owe the idea which I have developed to the above-named memoir (though its author has abandoned it,

[1] Geol. Mag. 1880, p. 404.
[2] *Ibid.* 1883, p. 199.
[3] Rep. Brit. Assoc. 1886 (Birmingham) p. 601.
[4] Geol. Mag. 1890. pp. 52 & 235.
[5] *Ibid.* 1888, pp. 54 & 285.
[6] These observations have been continued when opportunity occurred in later visits to the Alps.
[7] Geol. Mag. 1895, p. 75.

as I think, on insufficient grounds), but I have collected my facts and drawn my conclusions from them as far as possible in an independent spirit.

The following is a very brief summary of past work:—The Bunter Pebble-beds occupy nearly all the northern part of Cannock Chase (till lately a wild moorland, but now to a great extent enclosed), often practically forming the surface of the ground. Pits, opened for road-metal and gravel, are fairly numerous, some shallow, others 20 feet or so in depth. Those which I have examined are scattered about from Beaudesert Park to the Satnall Hills, a zone about 5 or 6 miles long and 2 or 3 broad.

Thus I have tested a fairly large area.[1] Moreover, during the earlier part of my work these pebbles were used in making new roads on the Chase, and thus fragments in plenty were spread out to view. The pebbles vary much in size. Those from a horsebean to about 2 inches in diameter are abundant; very many are larger, from 3 to 4 inches long being a common size; a few run still larger, up to 6 inches, and occasionally exceed that by an inch or two. In a very few pits they appear to be generally either above or below the average; but as the deeper excavations sometimes show beds of coarser, alternating with those of finer materials, I cannot venture to draw any inference from this observation.

They lie in a matrix of sand, composed almost entirely of quartz-grains, not conspicuously rounded, and more or less coated with reddish iron-oxide; they are very commonly in contact; indeed, I think that a large one is usually touched by two or three others. Not seldom they are indented, the 'pits' in the hardest quartzite-pebbles being as a rule extremely shallow, often barely perceptible, while on some of the mudstones they are conspicuous.[2] Beds or seams of sand are intercalated, though as a rule rather sparingly. These are lenticular in habit, generally thin,[3] and they may be seen inosculating with the pebbly layers. In short, whatever may be the origin of these Bunter deposits, they are wonderfully like the gravels in the lower valleys of the great Alpine rivers.

II. Petrography of the Pebbles.

Some of the more conspicuous rocks occurring as pebbles in the Bunter Conglomerate have been already described, but since 1883 I have paid more special attention to two groups—the felstones and the dark green to nearly black pebbles. It may be well, however,

[1] I have also seen something of the pebble-beds in Trentham Park, in the region of the Lower Mersey, at Nottingham and still farther north, besides examining collections from Lancashire made by the late Mr. G. H. Morton and Mr. Bolton, of Owens College, and from Nottingham by Mr. J. Shipman, to whom I return my best thanks.

[2] See T. Mellard Reade, Geol. Mag. 1895, p. 341, for an excellent plate of the pitted pebbles and a discussion of their mode of formation. See also Proc. Liverpool Geol. Soc. vol. vi (1892) p. 418.

[3] I do not remember to have seen them exceed 4 feet in thickness.

to enumerate briefly all the principal varieties. Vein-quartz and quartzites are the most abundant. The former are usually white, and very rarely they include black tourmaline, which in one specimen forms a tufted group of acicular crystals, nearly $\frac{1}{4}$ inch across.[1] Some varieties are cellular, and show minutely crystalline quartz; some are more chalcedonic in texture (one of them tinted green in places, probably by malachite). Another set, apparently connected with friction-breccias, will be more conveniently noticed later on.

Of the quartzites little more need be said. The cementation is so perfect that the individual grains are often difficult to see with the unaided eye, and the fracture is sometimes subconchoidal.[2] The colours vary, ranging from almost white—a pale buff or grey—to a dark tint, and (seldom) a greenish-grey; others are a dull red, light to fairly dark, and the characteristic 'liver-coloured' variety is not rare. These quartzites sometimes are speckled with fragments of red felspar, and thus graduate into the finer varieties of the quartz-felspar grits. The latter are generally uniform in grain, but occasionally more irregular. They vary from fine to rather coarse, and, as already said, exactly resemble the Torridon Sandstone of the North-western Highlands.[3]

Pebbly quartzites are found, the pebbles being usually vein-quartz, the matrix often rather dark. Besides these, grits of various kinds are fairly common, varying from quartzites to hard sandstone. One or two remind me of pebbles from the Permian of Leicestershire, which have been described by Mr. H. T. Brown, F.R.S.[4] Some are banded, and may perhaps belong to the group already described. Others, often reddish, might come from Ordovician, Silurian, or even later systems.

Fossiliferous pebbles are not common. In the true quartzites I have seen only worm-tubes, and these in about four specimens; from the grits I have collected, since 1883, three with other organic remains, but for these pebbles I have not specially sought, as they have already received considerable attention. As, however, it seemed very desirable that the identification of the fossils should be authoritative, I availed myself of the kindness of Mr. E. T. Newton, F.R.S., who has sent me the following notes:—'(A) *Orthis budleighensis*, *Orthis* sp., and a trilobite-fragment. B (1) *Atrypa reticularis*; (2) internal cast, probably *Atrypa*; (3 & 4) *Euomphalus?*; (5) *Strophomena* sp.; (6) *Favosites* sp.; (7) turbinate coral; (8) *Cornulites serpularius*. (C) In two pieces; cast of branching coral, probably *Alveolites repens*, or perhaps *Favosites*.'

[1] A quartz-pebble containing a crystal of tourmaline is recorded by Mr. S. G. Perceval as found at Sandford-on-Thames, near Oxford (I presume in Drift), Geol. Mag. 1870, p. 96.

[2] I have picked up one or two showing a cone-structure like that easily produced in flint by a blow.

[3] Geol. Mag. 1880, p. 405.

[4] Quart. Journ. Geol. Soc. vol. xlv (1889) p. 1.

Of these (A) is a fairly flat slab (with a small portion broken off at one end) coming from a smooth ellipsoidal pebble of a light-coloured, slightly micaceous quartzite. It measures rather more than 5 by a little less than $3\frac{1}{2}$ inches, the average thickness being nearly 1 inch. Lithologically it resembles those already found with this species of *Orthis* in the Midlands, and, as Mr. Newton remarks, 'is a typical Budleigh-Salterton pebble,[1] with the little *Orthis*, specimens of which (more than a dozen in all) are seen on each surface.' At that place, as the late Dr. Davidson remarked, this *Orthis* is the most abundant fossil: 'occurs also *in situ* . . . at Gorran Haven in Cornwall. . . has been found by Mr. Perceval at Sparkbrook, near Moseley, Birmingham; by Mr. W. J. Harrison at Counterthorpe, about 5 miles south of Leicester; by Mr. Jennings near Nottingham; and by the Rev. P. B. Brodie in the Drift near Warwick.'[2] I have found it, prior to 1880, on Cannock Chase.[3] It is abundant in Normandy at localities mentioned by Davidson, in beds of the age of the Grès de May (Bala).

(B) is a fragment, measuring roughly $3\frac{1}{2}$ by $2\frac{1}{4}$ inches and $\frac{1}{2}$ inch thick, from a flat pebble with a fairly smooth surface. It is a hard gritty mudstone or fine-grained felspathic grit, of a reddish-brown colour, reminding me of certain Upper Llandovery rocks. Mr. Newton remarks: 'there can be little question as to this specimen being of Upper Silurian age, and most probably Llandovery or Wenlock.'

(C) Two small fragments from a rounded pebble of a rather similar rock. The fossils are badly preserved, though apparently rather abundant. Mr. Newton remarks: 'most likely Upper Silurian.'

A number of other sedimentary rocks, such as hard mudstones, may be mentioned here. They usually vary in colour from olive-grey to brown, are sometimes slightly micaceous, occasionally banded, and resemble sundry rocks of Ordovician or Silurian age. Crinoidal chert occurs, but is rare; also fragments of grey limestone, this being, I think, more frequent near the base of the conglomerate, where somewhat angular fragments are more common, and the matrix is occasionally cemented by carbonate of lime. One certainly, the other probably, represents the Carboniferous Limestone. Traces of galena (rarely) and of malachite (more often) may be detected.

Felstones.—Some varieties of the felstone-pebbles were described in 1883, but I have collected many since that date. Altogether I have found at least three dozen varieties or species, but cannot speak more precisely, as I have mislaid the specimens from which slices were cut prior to 1883.[4] Those subsequently collected

[1] The remark does not refer to the deposit as a whole, but to the fossiliferous pebbles.

[2] T. Davidson, Palæont. Soc. Monogr. 'Brit. Foss. Brachiop.' vol. iv (1874–82) p. 360.

[3] Geol. Mag. 1880, p. 406.

[4] *Ibid.* 1883, p. 199.

number about thirty. I have had a few more sliced, and written a description of all; but, as many are of a commonplace character, I think that it will suffice to give a brief general summary, with a more detailed account of a few characterized by features of special interest.

These pebbles vary from subrotund to very well rounded; commonly they do not exceed about a couple of inches in diameter, though occasionally they may attain 3 or 4 inches. In texture they vary from perfectly compact to very minutely granular, one or two being almost microgranites, exhibiting in fact all the forms covered by the field-term felstone. The majority, especially of the more compact, contain grains of quartz, rather sparsely distributed, and about as big as the head of an ordinary pin, which is often found to be corroded by the groundmass. Felspar also is present, commonly in crystals measuring about $\frac{1}{10}$ inch across, but in one or two specimens it is more than $\frac{1}{2}$ inch. It is generally too much decomposed to allow of the species being determined on microscopic examination. A few specimens contain a dark mineral—either hornblende or tourmaline; in one or two biotite is present. The matrix in the majority is red, generally pale rather than dark, and some of the latter tint evidently are more basic than the ordinary kinds. In others it is grey or greenish-grey.[1] In fact, the collection includes devitrified rhyolites, dacites, felsites, and porphyrites; none of them, I think, being basic enough to be called basalts, and the majority distinctly acid.

A few specimens deserve a little fuller notice. One, a pebble from Style Cop nearly 3 inches in diameter, is a compact cherty-looking rock, traversed by thin quartz-veins. With ordinary light under the microscope it resembles a glass in which slightly greyer streaks are indicative of a fluxional structure. With crossed nicols the rock proves to be microcrystalline, as if it were entirely composed of chalcedonic quartz, the largest grains not exceeding ·004 inch in diameter. Scattered in this as a matrix are a few three or four times that size, which in outline resemble felspar, though they are now composed of microcrystalline quartz. I observe a certain resemblance to specimens from Treffgarn and Roche Castle (Pembrokeshire) which are now admitted to be acid volcanic rocks, subsequently affected by siliceous springs.

Another specimen (from Baland's Pool Pit) is unique. The matrix is very dark and compact, like a devitrified glass; this is irregularly crowded with reddish spherulites, often nearly ·2 inch in diameter. These, on microscopic examination, appear of a brownish colour, opacite being deposited between the radii. They are often composite, sometimes broken, being either actual fragments or recemented. A few crystals of felspar are present, mostly orthoclase, in one instance showing a granular structure, with some grains of quartz, more or less angular; these, in one or two cases, are pierced

[1] One with a compact grey matrix, in which are small grains of quartz and a small whitish felspar, is numerically commoner than the red kinds.

by the groundmass, and one is the centre of a spherulite. The groundmass is speckled with opacite, is imperfectly perlitic, and is devitrified, being a mass of very minute crystalline granules. The rock differs from the devitrified pitchstones of the Wrekin district, and I have never seen one like it in Britain. (See Pl. XX, fig. 1.)

Five varieties, containing more or less tourmaline, were described in 1883[1]; others have been subsequently obtained, two of them showing a fluxional structure, accentuated by the presence of darker streaks. In one, small and rather decomposed, the tourmaline has been determined by microscopical examination of the powder. A slice has been cut from the other (Style Cop), a flattish pebble, rather subangular, of a pinkish-grey colour, and streaked like the last-named, though not quite so frequently. The parts between the streaks seem to contain some minute microliths of tourmaline sparsely scattered, and exhibit a delicate fluxion-structure (devitrified). The dark streaks are formed of divergent bunches of rather small needles of this mineral (the indigo-coloured variety); see Pl. XX, fig. 3. Here and there, in an 'eye,' we find a few granules of a brownish mineral, with some resemblance, except in shape, to rutile, and perhaps more to cassiterite.

Another specimen (Style Cop) with a microcrystalline matrix contains a large quantity of tourmaline, granular and acicular, both brown and blue, the former occasionally enclosing the latter. (See Pl. XX, fig. 2.) In some cases the original mineral probably was felspar, but in others the tourmalines are grouped about or even enclosed between the cleavage-planes of a very brown micaceous mineral. Possibly the rock once contained biotite, which has been converted into tourmaline and a mica allied to lepidolite.

A third pebble (Baland's Pool Pit) is a reddish felstone with dark spots, almost like ink-stains. This, under the microscope, exhibits a devitrified groundmass, in which tourmaline is locally interspersed with quartz, as though it had replaced a felspathic constituent; but it also occurs in patches which resemble in outline a rather irregularly-formed biotite. Some similar patches now consist of a more or less tufted chloritic mineral, interspersed with ferrite-grains; while others of the same external shape are brown tourmaline, sometimes with similar enclosures. In one case part of a grain is distinctly (altered) biotite, while the other is no less distinctly tourmaline; that is, it exhibits the conversion of a biotite into tourmaline. In some grains of the latter mineral small black needles are arranged parallel with the longer sides, and apparently indicate the position of the cleavage-planes in the original biotite. That may be seen also in the grain mentioned above, just at the parts where the tourmaline has almost replaced the micaceous mineral. (See Pl. XX, fig. 4.) These two specimens fully confirm my interpretation of the three described in 1883 (*loc. cit.*) to which they are not distantly related.

[1] Geol. Mag. 1883, p. 199.

Dark Pebbles.—In my last paper I referred to certain pebbles, compact to minutely granular, varying from dark green to black, more often under than over 2 inches in diameter. To these of late years I have paid more attention. Microscopic examination proves them to include more than one kind of rock, some of which I proceed to describe.

A fairly rounded, minutely granular, black pebble (Style Cop) is a fine-grained grit composed of angular quartz-fragments, among which are one or two minute zircons, and interstitial matter so blackened as to conceal its exact nature, with a few (secondary) crystals of iron-oxide. Another (North Pit, Style Cop) about 2 inches in diameter, dark purplish-brown and minutely granular, shows distinct grains of quartz, generally angular, outlined by black granules, which also permeate the interstitial quartz. A third pebble from the same hill resembles a fine-grained quartzite, with a few very minute flakes of colourless mica, brecciated and then cemented by minutely crystalline quartz, full of opacite.

A fourth specimen (road on Racecourse) consists mainly of quartz (large subangular grains in a microcrystalline matrix) and minute flakes of a rather dark micaceous mineral; the whole suggesting a rock so much crushed as to assume a 'mylonitic' structure.

Two small dark pebbles (one from the Satnall Hills, the other from the Chase near Rugeley) resemble chert, traversed with minute quartz-veins. The structure under the microscope is that of a chert, and the former one is somewhat distinctly banded.

In both we see a number of small bodies circular or oval in shape, the inner part being slightly different from the outer. Suspecting these to be very ill-preserved radiolaria, and wishing to make sure, I trespassed (not for the first time) on the kindness of Dr. G. J. Hinde, F.R.S., and met with the usual generous response, which is to the following effect:—'The rounded bodies in the slice from the Satnall Hills are, in my opinion, casts of radiolaria, and some of the smaller circles may be cross-sections of sponge-spicules. I do not see any structure preserved, but this happens, unfortunately, in the large majority of radiolarian cherts. The only character which differentiates the slice from the usual radiolarian chert is that the circular bodies are generally smaller than the casts in the Palæozoic radiolarian cherts that I have hitherto examined. Many of the casts, moreover, seem to have been squeezed out of shape. The other slide appears also to be a true radiolarian chert.' (See Pl. XX, fig. 5.)

Other dark pebbles contain a fair quantity of tourmaline. Occasionally it is very minute, rather filmy in aspect, not strongly pleochroic, and of a pale brown colour. But a little acicular indigo-tourmaline commonly can be detected, and is usually well-developed in any vein. Possibly the mineral of the matrix may be sometimes a brown mica, and I think it very probable that tourmaline often has replaced that mineral. One pebble (Style Cop) appears to have been a rather fine-grained felspathic quartz-grit, in which the aluminous constituent has been converted into a granular brown

tourmaline, rarely acicular in habit or blue in colour. Another (same locality) is much more minute in structure, and the tourmaline is still less characteristic, though here and there it can be identified. A third (same locality) is mainly composed of this exceedingly minute filmy mineral, of which one would be dubious, did not small characteristic tourmaline-needles spread out from it into a vein. Probably the rock was originally a mudstone. A fourth specimen is banded, and may be described as combining the third with the first: thoroughly characteristic tourmaline only appearing in a vein. One or two other slices contain a trace of tourmaline, but these four are my best specimens.

In this connexion I may mention a specimen which is very like, both macroscopically and under the microscope, to one of the light- and dark-banded tourmaline-and-quartz rocks of the 'killas' in Cornwall. Had it been given to me as coming from that district I should have accepted it without question. This, however, was not my only reason for collecting the specimen; there was another, namely, that I think it comes, not from the Bunter, but from the Drift. It was a fairly angular block, at least 25 cubic inches in volume, and it lay on a heap of stones near a woodman's cottage, at the entrance of the copse called Huntington Gap; that is, near to the edge of the Driftless area of the Chase, and in one of the most lonely parts, for, I think, there is no other cottage within a mile. Among the trees erratics (Welsh and North Country) soon become fairly common. The specimen accordingly presents the following dilemma:—If from the Bunter, how did it escape rounding? If from the Drift, where was its home? On the latter supposition, either rocks of Cornish type must occur in Scotland or erratics sometimes came from the south, as well as from the north and west, in the Ice Age.

A small group of pebbles remains to be mentioned. These are breccias. Certain of them seem to be only vein-quartz and not worth minute study. Others show angular or subangular compact fragments in a black matrix. I have examined three specimens. In two, the fragments prove, as I expected, to be vein-quartz, crushed probably by earth-movements: the matrix being composed of smaller fragments of the same, cemented by secondary quartz and tourmaline. The vein-quartz includes abundant cavities (rather large in one specimen, smaller in the others), which contain bubbles. From these the secondary quartz is usually free. The tourmaline is both brown and blue, the latter as usual distinctly acicular, and its needles occasionally appear to have inserted themselves for some distance into the vein-quartz. The matrix of the second specimen more nearly resembles a tourmalinized mudstone, as described above, and has a slightly foliated aspect. In the third specimen the matrix is mainly composed of minute granules of tourmaline, here and there passing into clusters of prisms or needles of both tints. The fragments are speckled with ferrite, and occasionally include grains of quartz (one of which is pierced by the matrix) containing numerous cavities with bubbles variable in size, and sometimes even

occupying about one third of the space. These fragments, with crossed nicols, exhibit a chalcedonic structure, and I think that they represent a silicified pitchstone. In these tourmaliniferous rocks I have occasionally come across a few granules, often associated, of a honey-brown colour, and a rather high refractive index, which may possibly be cassiterite.

One breccia remains (Baland's Pool Pit) which microscopically resembles a fairly well-preserved, reddish gneissoid granite. Microscopic examination shows it to be a coarsely crystalline, almost binary granite (some microcline), pressure-modified, and recemented by mosaic quartz, with some interspersed opacite or ferrite, associated occasionally with a prismatic, colourless, microlithic mineral, apparently monoclinic, and possibly a very little epidote. The rock might be derived from an Archæan mass. Both granitoid rocks and crystalline schists do occur in the Bunter Conglomerate, but are rare and generally very rotten. This one has probably been preserved by the infiltration of silica.

III. Transport of the Pebbles.

Such being the evidence which I have been able to collect as to the materials of the Bunter Pebble-beds in the Midlands, we have next to consider by what agency they have been brought thither and from what source or sources they have most probably been derived.

The former of these questions need not detain us long. They cannot, as I have more than once pointed out, be lacustrine deposits; hence they must be either marine or fluviatile. Mr. Mellard Reade maintains the former view,[1] and no doubt this would avoid some difficulties, but these beds, as has been shown by myself and others,[2] are very unlike marine deposits, differing most of all in being at once widespread and thick, and so not resembling any shingle-beds of which I have knowledge. Hence they must be fluviatile; but this admission, which now seems general, involves certain consequences, to which I shall refer presently, since they seem to have been frequently overlooked.

In discussing the second question, the source of the pebbles, I must be understood to refer to the more numerous and distinctive rocks, for the Midland Bunter contains so great a variety that I suspect them to represent a very wide drainage-area. As a large river receives many tributaries, it may very well happen that, while the bulk have come from one quarter, say from the north, others have been contributed by districts lying more nearly east and west. In this particular case the south only would seem to be improbable, if not excluded, as a direction.

Any locality which claims to be the source of these pebbles must satisfy two conditions: (1) it must have an adequate supply of the right kinds of rocks, and (2) be capable of feeding rivers large

[1] Geol. Mag. 1889, p. 549; *ibid.* 1890, pp. 155 & 260.
[2] Rep. Brit. Assoc. 1886 (Birmingham) etc.

enough to transport the materials. I have estimated the Midland Bunter—and am not aware that I have been convicted of exaggeration—as a mass equal to a mountain-range 65 miles long, 4 miles across its base, and 1 mile high, the pebbles alone representing a similar range 20 miles long, 2 miles broad, and fully 1000 feet high. As this requirement is irreconcilable with some hypotheses, I am surprised that it has not been disproved, or at least disputed, by those who have advanced them.

IV. Possible Sources of the Pebbles.

(1) North Wales.—The Principality might contribute sand enough, if the Old Red Sandstone were heavily taxed; but it has neither the quartzites nor the quartz-felspar grits, nor the right felstones, at any rate in quantities worth a moment's consideration; nor can it ever have supplied them, because, as the region is composed of rock older than the Trias, they should still be visible at the surface.

(2) The Longmynds.—In the Midland region the only rocks resembling the ordinary Torridon Sandstones occur in the Longmynds, where they are exposed over a considerable area, especially in the north-western part. Here I examined them in 1896, with my friend the Rev. E. Hill, and under the kind guidance of Prof. Lapworth. As these rocks have a very important bearing on the question before us I shall give some description of them, without, however, touching the controversies which exist in regard to their exact age and classification. The conglomerates and grits apparently overlie, in the district around Lyds Hole, a volcanic group, consisting chiefly of compact rhyolitic lavas, sometimes with 'pyromerides,' and presenting a general resemblance to those in the Wrekin district, for which the name Uriconian has been proposed. At the base of the 'Torridonians' are grits, seemingly felspathic, which are succeeded by a rather thick conglomerate (No. 1) composed of beds of pebbles parted by seams of grit, the latter not usually exceeding 2 feet in thickness. The pebbles (which, as far as I remember, are often about the size of a hen's egg) consist of vein-quartz, quartzite (not very abundant), old rhyolites (not rare), and a granitic rock, the matrix being apparently an irregular-sized quartz-felspar grit, sometimes curiously like the Torridon Sandstone. This is followed by a thick mass of rather friable purplish sandstone (probably tinted in parts by manganese), above which is another conglomerate (No. 2) with fewer sand-partings, but less strong than the lower one. It is thickly studded with subrotund pebbles, occasionally 4 or 5 inches in diameter, but more often from 2 to 3 inches, consisting of vein-quartz, quartzite, whitish to reddish or purplish, having as a rule a rather satin-like aspect on broken surfaces, and of streaky rhyolites. It is sometimes interrupted by seams of a rather ashy-looking grit. This is succeeded by a large series of grits, apparently more or less felspathic, which

becomes pebbly in places, not, however, including, so far as we saw, such well-marked beds as those just mentioned. In the neighbourhood of Castle Pulverbatch we found them becoming fine-grained, and interbanded with the usual argillites of the Longmynd.[1]

The following extract from my diary will show the impression produced by walking over a considerable area occupied by these beds[2]:—'On the whole, I am doubtful whether this can be the region which has supplied the quartz-felspar grit to the Staffordshire Bunter. The rock is more liable to small changes in the course of an inch or so; much of it is apparently rather richer in mica (biotite); the grains are perhaps a little more rounded than in the Bunter grit or in the normal Torridon; the quartzite in the pebbles differs slightly from that common in the Bunter conglomerate, though some varieties may be identical' (I did not see the 'liver-coloured' kind). Other difficulties are then mentioned, which I pass over for the moment. I collected a few specimens, including those which were most like the quartz-felspar grits of the Scottish Torridonian and of the Bunter Pebble-bed. These I have examined under the microscope. The first of them came from the middle of the lower conglomerate (No. 1) near Lyds Hole, and is very like the coarse Torridon Sandstone between Kinlochewe and the Loch Maree Hotel. It contains grains of dusty-looking quartz and of felspar (not much): both being probably derived from a coarse granitoid rock. (They are associated in one fragment, and another shows a micropegmatitic structure.) We find also some grains of composite quartz (? from veins) and many representing varieties of devitrified rhyolites.[3] The next specimen came from the Upper Torridonian on the way from Plealey to Castle Pulverbatch. Though it was not *in situ*, I took it because it more closely resembled a piece of ordinary Torridon Sandstone than any other which I found. Under the microscope we find that the fragments are more or less subangular, often about ·03 inch or a little less in width; quartz is fairly common, both in single and composite grains (the latter generally from veins, but possibly also from a crystalline rock); very little felspar occurs, but there is an abundance of fragments of volcanic rocks, some rhyolitic, many more or less ferrite-stained, and several blackened with opacite. One or two include spots of viridite, but the presence of cavities is doubtful. (See Pl. XX, fig. 6.)

The remaining specimens do not strikingly resemble Torridon

[1] An enumeration of the contents of the pebble-beds of this series (which I have only recently read) is given by the Rev. J. F. Blake, Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 398. My description is condensed from the notes written on the spot.

[2] Rocks resembling these, if they occur at all in the Staffordshire Bunter, are inconspicuous. Perhaps I should add that the quartzite of the Stiper Stones differs from the one typical of the Pebble-bed.

[3] I use the term rather loosely, to indicate rocks like those which occur about the Wrekin and near Pontesbury: that is, compact red lavas, varying probably from rhyolites to dacites, and perhaps sometimes not quite so rich in silica. A more precise determination would be needless, and often impossible without chemical analysis.

Sandstone. One represents the grits between the two conglomerates, and was taken from a fairly hard band from 200 to 300 feet below the second one. A long description is needless. The grains are commonly a little smaller than in the last specimen, and the slice contains a large proportion of 'volcanics' as already described, but perhaps fewer are blackened. Another specimen represents the lowest grit (under No. 1 conglomerate). The grains are rather smaller, and some of them have a slight green tinge, but otherwise it closely resembles the last described. The fifth specimen is from a fine-grained grit, associated with argillites, near Castle Pulverbatch. The fragments are yet smaller, and more distinctly angular, but it also is crowded with similar volcanic materials.

The foregoing samples, I think, suffice to give a fair idea of the composition of the Longmynd Torridonian. Some of their materials have been undoubtedly derived from coarse granitoid rocks, and it is also true that fragments of 'rhyolite' may be occasionally detected in the Scottish Torridonian. But they are not common; I am certain of their presence in two slices only, out of ten in my collection, and I do not detect them in any of six slices from Staffordshire pebbles, though they are present in one from the Bunter near Runcorn.[1] Thus the Longmynd Torridonians are quartz-rhyolite rather than quartz-felspar grits, and on lithological grounds alone cannot have been important contributors to the Staffordshire Bunter.

(3) Cornwall and Devon.—Whether Cornwall and Devon, even supposing a large extension southward and westward, could supply the sand is doubtful, if what remains is a sample of what has gone.

The Triassic pebbles, as exhibited at Budleigh Salterton, were described in 1895,[2] but I may add that the red quartz-felspar grit is practically identical, microscopically as well as to the unaided eye, with the Torridon Sandstone of Scotland, and that further study of the tourmaline-bearing pebbles from the Midlands reveals rather more resemblance to some rocks from Devon and Cornwall[3] than I had at first anticipated. But even now there is an overlapping rather than a general identity. The same variety of quartzite, as I then pointed out, occurs in both localities, but abounds in the former and is rare in the latter.

The quartzite dominant at Budleigh Salterton does not exhibit under the microscope any distinctive characteristic; though the grains are rather angular, more oblong, and smaller, perhaps also with less secondary quartz than in the Midland and Scottish specimens. The difference, however, in form is very marked, and I have never seen in Staffordshire one of the flat ellipsoidal pebbles characteristic of Devon. Besides this, whatever evidence we possess is hostile to the

[1] I have to thank Mr. Bolton, of Owens College, Manchester, for this and other pebbles from that locality.

[2] Geol. Mag. 1895, p. 75.

[3] I am indebted to Mr. J. J. H. Teall, F.R.S., for the opportunity of studying a number of specimens from this region.

idea of any continuity between the pebble-beds of the Central and Southern areas.

(4) Lake District and the Pennine Range.—Perhaps we might find materials enough in the Pennine Range for the sand, but neither the quartzites, nor the quartz-felspar grits, nor the tourmaline-rocks, nor the bulk of the felstones[1] occur in the Lake District, while it contains many rocks which we do not find in the Bunter conglomerate.

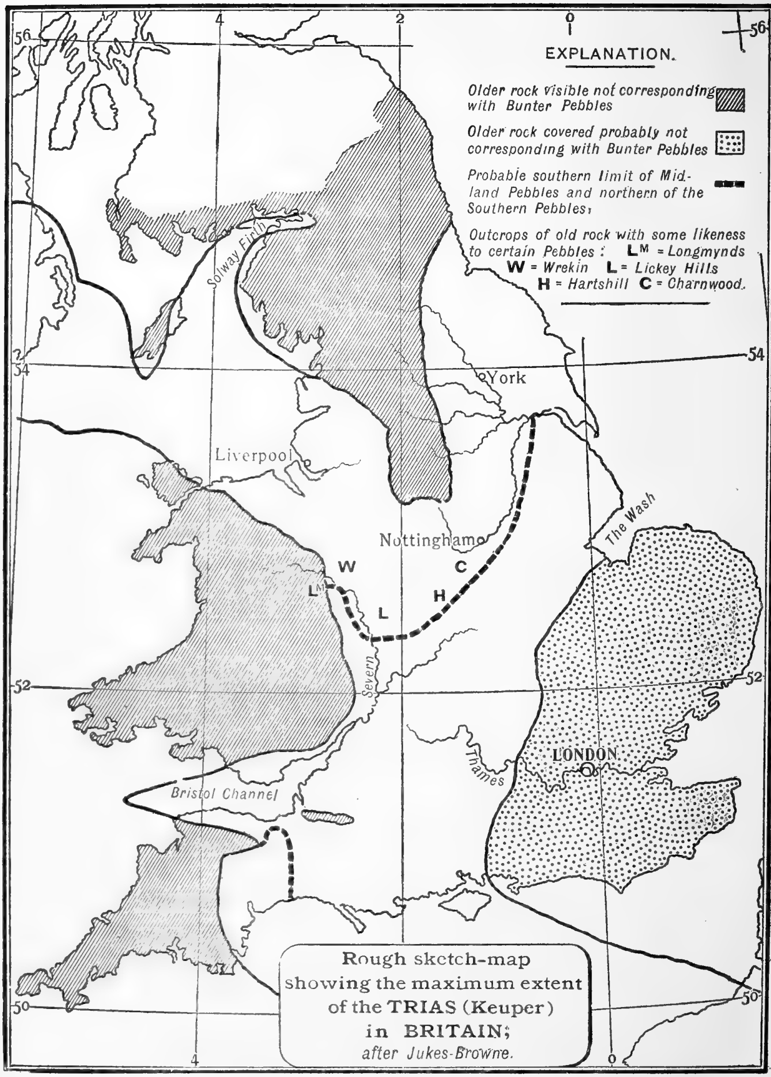
(5) The Midlands and the adjacent Covered Region.—The outcrops of Charnwood, Hartshill, the Lickey, and the Wrekin districts afford neither the right felstones nor the right quartzites. They do not include (and I have studied all) either the quartz-felspar grit or tourmaline-rocks. Charnwood rocks, though they have been detected in the Permian breccias of Leicestershire, do not, so far as I know, occur in the Bunter, and the characteristic felstones, which should be easily recognized, certainly have not reached Staffordshire. A quartz-felspar grit, though not of the right kind, was indeed struck beneath Keuper at Orton, in Northamptonshire,[2] but the borings at Burford in Oxfordshire, in the London area, in Essex and Suffolk, have not given a hint of the occurrence of any of the above-named rocks. They have only proved the existence of certain Palæozoics in great folded masses, and made it probable that the rest represents other systems of that era. The opponents, however, of a supply from the north urge that the rocks may be there, but buried. *Omne ignotum pro magnifico* is a true saying, as we shall presently see. Can any great quantity of the necessary rocks have been exposed in the early part of the Trias? The position of the Keuper at Charnwood, Hartshill, the Lickey, the Wrekin, and Orton shows this to be impossible. If it were so, we should expect their fragments to be abundant in the Permian breccia of Leicestershire, which is not the case.[3] Neither here, nor elsewhere in the Keuper, nor in the Lias, is there so much as a hint that large masses of these peculiar rocks existed anywhere in Central, Eastern, or Southern England. Hence, I maintain that even if the region where the Bunter was deposited had been interrupted or bordered by rocks of the right kinds, these must have formed comparatively small islands or insular ridges.

But, if this be true, then the Bunter deposits cannot be derived from Midland material, and yet be of fluviatile origin. We may, I presume, take it for granted that they are not a confluent group of little deltas. From Lancashire, all round the southern end of the Pennines to beyond the north of Nottinghamshire—I speak from personal knowledge—though slight local differences, as is to be

[1] I believe there are none, but as there is a slight similarity in one or two cases, I prefer the more guarded statement.

[2] H. J. Eunson, Quart. Journ. Geol. Soc. vol. xl (1884) p. 490.

[3] See H. T. Brown, Quart. Journ. Geol. Soc. vol. xlv (1889) p. 1; & T. G. Bonney, 'Midland Naturalist' vol. xv (1892) pp. 25 & 49.



Rough sketch-map showing the maximum extent of the TRIAS (Keuper) in BRITAIN; *after Jukes-Browne.*

expected, may exist, the dominant characters of the pebbles are unchanged. They must have been transported by a large river, or probably two (I regard the Devon pebble-beds as the delta of a third river), flowing with a current, the rate of which, when the pebbles were being moved, varied from 2 to 3 miles an hour. Such rivers cannot issue from limited tracts of land. We have now no English streams capable of producing the Bunter Pebble-beds. Their feeding-ground must either have been very large—continental, not insular in character—or the rainfall upon it must have been exceptionally heavy.

What evidence is there that any such region existed to the immediate east or south of the Midlands? None that I can find, but very much to the contrary. This, however, is not all; the Bunter pebbles imply, not only a large and strong stream, but also a long journey. Daubrée's well-known experiment showed that to round an angular fragment of a hard rock, such as a quartzite, into a pebble required a journey of nearly 16 miles. This, however, must be taken as only a minimum distance, for he subjected his materials to conditions which resemble those existing in an Alpine torrent, rather than in an ordinary strong stream. In the Alpine rivers, as I have shown, the pebbles, though the majority must have travelled from 30 to 60 miles and the materials are commonly softer than quartzite, are not usually so well rounded as those in the Bunter.[1]

Thus, on physical as well as petrological grounds, all those insignificant outcrops in the Midlands, even allowing them some enlargement—the hidden isthmus between Gloucestershire and Devon, the buried plateau under our eastern and south-eastern counties—are ruled out as inadequate; they, as a little study of a geological map, or of that appended (p. 300), will show, could not have given rise to streams of sufficient size and potency, unless we suppose the Bunter to have been a 'pluvial epoch.'

The hypothesis of a northward flow of the water, which evidently is favoured by Mr. Jukes-Browne,[2] lands us in more than one difficulty if we admit, as we are compelled to do, the river or rivers to have been large. Suppose for a moment the Bunter-beds in the circum-Pennine region to have been deposited by a stream which came from Devon, or from somewhere towards the south. If so, it was bifurcated by the Pennine range, which must have been a kind of promontory from a large mass of land to the north. Such bifurcation is not, perhaps, impossible, but it is unusual, and wants more foundation than an hypothesis. But, conceding the possibility, I ask—What became of the river?, for evidently it did not produce an inland sea till Keuper times. I have identified pebbles of Bunter quartzites and one or two of felstone, with plenty of vein-

[1] The evidence is given, and the applicability of the results to the Bunter indicated, in a paper 'On the Rounding of Pebbles by Alpine Rivers, etc.' Geol. Mag. 1888, p. 54. It is a curious fact that this paper has been ignored by the advocates of an 'adjacent' origin.

[2] 'Building of the Brit. Is.' 2nd ed. (1892) p. 192.

quartz, in the Lower Keuper conglomerate at Alderley Edge (1891). In the Keuper, also, I think that we can trace the gradual setting in of 'inland-sea' conditions. I am content to take Mr. Jukes-Browne's own map of Britain ('Building of the British Isles,' pl. facing p. 198) at this epoch, and ask whether it does not suggest that the inland sea then occupied valleys which once had opened towards the south? So far as I understand the physical geography of our region in the earlier and greater part of Mesozoic times, everything points to the existence of large land-masses towards the north and west, of which Scandinavia, Scotland, parts of Ireland, probably also Cornwall, Normandy, and Brittany are remnants.[1]

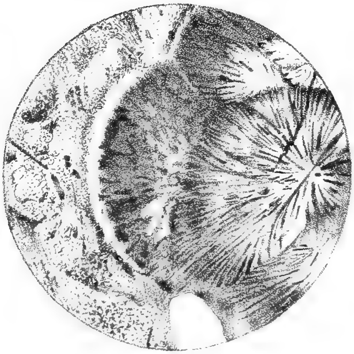
The quiet transition from Keuper to Rhætic, the disposition of the various sediments throughout the Jurassic period, the march of its fauna from the French to the British area, all point to land, probably continental, on the north and west, bordered or pierced by a sea opening towards the south-east. Reversals of drainage, of course, may occur, but I am not acquainted with any evidence to show that this happened either before or during the Mesozoic era. Did the Bunter rivers run northward, we might indeed exclaim with Tennyson:

> 'The hills are shadows, and they flow
> From form to form, and nothing stands.'

But in one direction we find the physical and lithological conditions very nearly satisfied—namely in Scotland. It is needless to repeat what I have published about the correspondence of the quartzites, the quartz-felspar grits, and the felstones generally in that country and in the Midland Bunter; I will only add that in 1892 I examined the conglomerates in the Lower Old Red Sandstone in the neighbourhood of Callander, at Rothesay, and at the base of the Carboniferous system near Brodick. In them pebbles of vein-quartz abound, such as we find in the Midlands, and I obtained, though more sporadically, varieties of the quartzites, the quartz-felspar grits (sparingly), and felstones, some of which appeared identical with those in the Bunter. These were mingled with a number of schistose grits in more or less angular fragments, with an occasional piece of schist or of granitoid rock. The latter, especially the schistose grits, which are rather perishable, are generally missing in the south, and the former set of rocks, I think, is rather more rounded there; but though the proportions are altered, many pebbles are common to the Scottish and the English conglomerates, and the matrix of the one is practically identical with that of the other.

The tourmaline-rock among the Bunter pebbles, I admit, presents a difficulty, for this mineral is rare in Scotland. It is not, however, unknown. Mr. Teall has shown me specimens from contact-metamorphic rocks at Knocknailing (New Galloway), in sillimanite-gneiss from Kincardineshire, and in pebbles of a quartz-schist which,

[1] I referred to this, and briefly indicated how the occurrence of some rocks identical with those that occur in Scotland might be explained, in Geol. Mag. 1895, p. 79.



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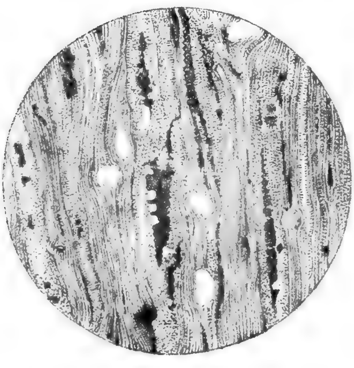

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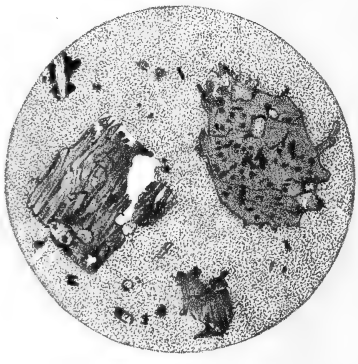

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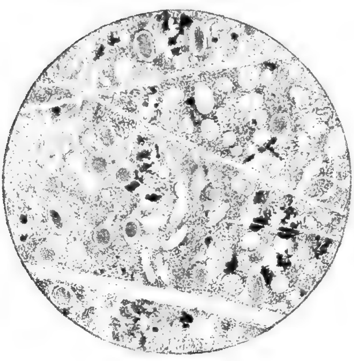

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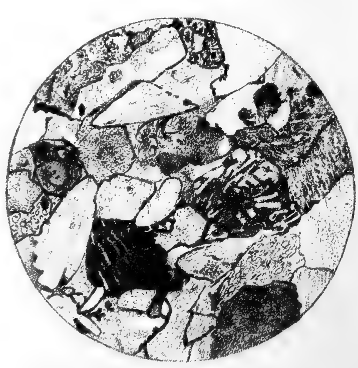

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E. Drake del. et lith. West, Newman imp.

SECTIONS OF BUNTER PEBBLES, &c.

except that this latter mineral is more abundant, much resemble some specimens from the Bunter. But, while admitting the difficulty, I think that this negative argument ought not to outweigh the large amount of positive evidence.

Thus physical and lithological considerations seem to make it highly improbable that the materials of the Midland pebble-beds can have been derived from the south-western region, and impossible that they can have come from any neighbouring district unless we assume that great beds of conglomerate are buried out of sight towards the east and south (which are wholly hypothetical), and a very exceptional rainfall, for which we have no evidence. I have taken some pains to collect my facts, have endeavoured to treat them inductively, and am now content to leave the subject, unless new discoveries compel me to reconsider my conclusions.

EXPLANATION OF PLATE XX.

(All figures $\times 18$ diameters: 1 to 5 inclusive, from pebbles in the Bunter Conglomerate.)

Fig. 1. From Baland's Pool Pit. Spherulitic pitchstone (devitrified). The spherulites are coloured with ferrite: the groundmass is speckled with opacite, is perlitic in places, and shows, with crossed nicols, minute devitrification-structure. The white spot at the bottom is a hole in the slice. (P. 291.)

2. From Style Cop Pit. Tourmalinized microgranite. Crystals of mica (probably biotite) replaced wholly or partly by tourmaline: the dark lines, indicative of original cleavage-planes, being formed by microliths of dull green tourmaline (schorl). The microcrystalline groundmass consists mainly of quartz and tourmaline (brown and dull green), the latter mineral doubtless generally replacing felspar. (P. 292.)

3. From Style Cop Pit. Rhyolite with fluxion- and minute devitrification-structure, the former indicated by numerous minute lines of ferrite and by larger, irregular, elongated streaks composed of tufted needles of schorl. The white spots are mostly holes, but a very few small grains of quartz, and some small crystals of felspar, partly converted into tourmaline, occur in the slice. (P. 292.)

4. From Baland's Pool Pit. A mica-felsite. The large grain on the right is brown tourmaline, containing some granules of iron-oxide; that on the left (partly torn away in grinding) consists of flakes of a rather pale green chlorite, slightly tufted, but with a general disposition parallel to the original cleavage of the mica. In other parts of the slice needles of schorl are mixed with the chlorite, showing stages of change from biotite to tourmaline. The devitrified groundmass appears to consist mainly of felspar in ill-defined and rather irregular granules. In this case, conversion into tourmaline seems practically restricted to the biotite. (P. 292.)

5. From a new-made road (probably from Racecourse Pit). Radiolarian chert. The organisms are readily distinguishable; the groundmass exhibits a very minute chalcedonic structure, and is slightly speckled or stained with ferrite. Very thin quartz-veins cross the slice. (P. 293.)

6. Longmynds, near West Hill. Specimen most like a typical Torridon Sandstone. This part of the slice is mainly composed of somewhat rounded grains of volcanic rock, now apparently devitrified (varieties of 'trachytes') with a little felspar and some quartz. Though the volcanic material varies in amount, it is everywhere dominant. (P. 297.)

Discussion.

Mr. Strahan said that he was glad to see the Author once more engaged upon the interesting problem of the origin of the Bunter sediments. He thought that a comparison of them with the breccias at the base of the Keuper Marls was instructive. The latter consisted of material derived from the cliffs against which they rested; they seemed to have travelled a few yards only, and resembled scree that had fallen into water. The Bunter pebbles, on the other hand, bore evidence of a long journey, and generally were so perfectly rounded as to suggest that they must have been derived from some pre-existing conglomerate.

As to the direction of their transport, he recalled the fact that the pebbles decreased rapidly in size from south to north. The shingle-beds of Shropshire passed into thick sandstones with a few insignificant pebbly seams in Cheshire and Lancashire. This increase in the thickness of the sediments pointed to the area of maximum subsidence having lain to the north, and both this and the distribution of the pebbles suggested transport from the south. This was an old objection to the Author's theory, and presumably would be met by him. His precise observations on the composition of the pebbles could not fail to be of the greatest value in the investigation of this problem.

Prof. Sollas remarked that the Author's theory of the fluviatile nature of the Bunter Beds was becoming very generally accepted both in this country and abroad. The case presented in favour of a northern origin for the bulk of the material forming the Pebble-beds was no doubt a strong one: but it was not without its difficulties, and the objection urged by Mr. Strahan required to be met. A river-system might include tributaries from very different sources, and the speaker was disposed to think that some of the Bunter pebbles of the Midlands had been brought from the south. The remarkable similarity between the material of the pebbles of Budleigh Salterton and that of the Grès de Mai could not fail to impress the observer: it was not merely lithological, but palæontological; and few would dispute that the Budleigh-Salterton pebbles had a southern origin. But it was admitted that pebbles as similar, lithologically and palæontologically, to the pebbles of Budleigh Salterton as these are to the Grès de Mai occurred in small numbers in the Midland district. Again, while the Bunter thickened from the Midlands towards the north-west, in Devon it thickened towards the south; and thus precisely the same kind of evidence which was adduced in favour of a northern origin also existed in favour of an origin from the south. During the deposition of the Bunter, South Wales and Somerset formed a tract of dry land, which would have intercepted the current of a river flowing northward from Budleigh Salterton; but this barrier might have been easily turned on the east, and the stream of Grès-de-Mai pebbles might possibly have passed along a line between the Mendips and the Wiltshire Downs. The difference in form of the Budleigh-Salterton pebbles and those

of the Midlands was no insuperable objection to their having travelled from a common source. Disciform pebbles could not be transported so readily as spherical ones, and thus the presence of rounded pebbles more to the north, and flatter ones more to the south, was in complete accordance with the views advocated by the speaker.

The Rev. Edwin Hill cited instances of the work required for rounding materials.

Mr. Walcot Gibson said that, without wishing to enter into the general questions raised by the paper, he would point out that the very limited exposure at Barnt Green showed how great a variety of rocks occur in proximity to the Lickey quartzite; while in North Staffordshire and in the Midlands generally the coarse shingle-beds of the Bunter cling to the axes of elevation, and are absent or but feebly developed in the great basin of Cheshire and South Lancashire. The great unconformity at the base of the Trias everywhere visible in the Midlands must always be taken into account in speculating upon the physiography of the land in pre-Bunter times.

Mr. Clement Reid remarked that the possibility of derivation of the pebbles from the east was rejected by the Author. The character of the older rocks hidden beneath the Chalk between Harwich and the Wash is still, however, entirely unknown, though the abundance of large Palæozoic and metamorphic pebbles in the Pliocene river-gravels, which are derived from the east, points to an area of ancient rocks formerly exposed in that direction. The quartzites, etc. in the Pliocene rocks do not much resemble those exhibited by the Author.

Prof. Watts, with reference to the rounding of the Bunter pebbles, pointed out that pebbles—mainly of limestone, it is true—were fairly well rounded on their short journey from the Maritime Alps to the Mediterranean. The rounding of the pebbles might be consistent with a Midland origin if they had been derived from a conglomerate, and he wished to ask the Author whether he was able to say that the 'Torridonian' conglomerates of the Longmynd were incapable of yielding the dominant rock-types of the Bunter pebbles.

The President said that the Torridonian conglomerates of the North-west of Scotland contained pebbles of the same types as those described by the Author—vein-quartz, quartzites, quartz-felspar, grits, felsites, chert, and 'schorl-rock.'

Mr. W. Whitaker and Mr. H. B. Woodward also spoke.

The Author said that he had examined some of the Keuper breccias to which Mr. Strahan had called attention. Angular fragments of local rock were often commoner in them, but he thought that when these breccias were formed the conditions had altered. The difficulty about the less abundance of pebbles when the Midland Bunter was followed northward was undoubtedly a real one, but of that he himself had written in 1890, pointing out that it was counterbalanced by the great thickening of the Bunter as a whole in the same direction. Of this apparent contradiction he suggested an explanation. Prof. Sollas had

suggested that some of the pebbles might come from the north, others from the south. Now the fossiliferous pebbles, which it was urged came from the latter direction, had been found at least as far north as Nottingham; so that it was difficult to imagine the river-system which would bring about such an extraordinary crossing of materials. Prof. Sollas had been misinformed as to the relation of size and shape in the Devon pebbles. There large and small were disc-like; both, in the Midlands, were generally egg-like. He could not understand how, by any survival of the fittest, the small minority, in beds not exceeding 100 feet in the one case, could become the majority in beds of thrice that thickness in the other. He knew the district of which Mr. Gibson had spoken, but failed to see the significance of the alleged thickening of the pebble-beds about the South Staffordshire Coalfield, unless Mr. Gibson looked upon that as the source of the pebbles. He had seen something of the East Anglian gravels, mentioned by Mr. Clement Reid, but, having regard to the very different dates of the two, did not see that they had much to do with the present question. The materials also were very different, as were the rocks of the Ardennes region, from that of the Bunter pebbles. To Prof. Watts he replied that he had already been careful to point out, so long ago as 1888, the difference in the action of mountain-torrents and strong streams; that there was not room in the Midlands for the former, and, as he had shown in his paper, no probability of the latter coming from any but a northern direction. The Longmynd conglomerates were inadequate as a source of the quartzite-pebbles; the Torridonian he had shown to be a quartz-rhyolite rather than a quartz-felspar grit; and the argillites were apparently absent from the Midland Bunter. Its more important constituents occurred to the north; all other localities suggested were supported by hypotheses, not by facts.

18. *The* Rocks *of the* South-eastern Coast *of* Jersey. By John Parkinson, Esq., F.G.S. (Read March 7th, 1900.)

Contents.

I. Introduction.

In a recent communication to this Society[1] I described the intrusion of a granite into a diabase at Sorel Point, on the northern coast of Jersey, and in concluding remarked on another parallel case to be found on the southern side of the island. It is to this that the present paper relates. The rocks from north and south, both intrusive and intruded into, show a resemblance one to another sufficient to indicate that they are closely related. The interior of the island is occupied by the rather varied assortment of igneous and sedimentary rocks depicted on M. Noury's map.[2]

From the town of St. Helier's to La Rocque Point, the south-eastern termination of the island, the receding tide exposes to the view of an observer standing on the low shore an assemblage of jagged rocks which stretch far out towards the horizon. Near the centre of St. Clement's Bay an intrusive granite is found about high-water mark, and forms at the western end the more outlying crags of Le Nez Point. At Grève d'Azette, the next bay to the westward, it again approaches the shore. Diabase and other closely-related rocks make up Le Nez itself. At the junction of the two the granite sends innumerable offshoots and dykes into the older rock, which are well seen to the west of Le Nez. Generally these dykes are clearly cut and well defined; but occasionally peculiar rocks make their appearance, so similar to those non-homogeneous and mixed rocks which I described from Sorel Point (*op. cit.*) that we cannot doubt, after a comparison between them, that a local incorporation of fragments of the diabase has taken place. So far the matter appears clear enough, and it is only when the diabase itself is studied that complications, arising from its non-homogeneous

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 430.
[2] 'Géologie de Jersey,' 1886.

character, become apparent. This is shown by the clear evidence of another brecciation, somewhat earlier than that caused by the granite and exhibiting certain important differences. The rather interesting rocks resulting from this intrusion by a process of melting and incorporation are confined almost entirely to the neighbourhood of the headland between Grève d'Azette and St. Clement's Bay. Westward of these evidences of brecciation are found again everywhere, but the variations in the older rock are not marked, and the invading rock differs in several particulars from the granite to the east.

For purposes of description, the coast including Grève d'Azette and the western part of St. Clement's Bay will be termed the Eastern District, that of Havre des Pas and St. Elizabeth's Castle the Western.

II. The Eastern District.

The oldest rock of the coast is a diabase so closely resembling the one of Sorel Point that a detailed description is unnecessary. The original colourless augite is now almost entirely replaced by brownish-green hornblende, with which a rather fibrous mica is associated in some slides, no doubt the result of a further change. The augite was later in consolidation than the felspar, producing the common ophitic structure. In one section of a specimen from Grève d'Azette, the replacing hornblende shows a faint striation making an angle of 70° to 72° with the prismatic cleavage in sections approximately parallel to the clinopinacoid, and therefore probably the basal striation of the original augite. The specific gravity of this specimen is 2·88.

(1) Characters of the Earlier Acid Intrusion.

To the westward of the Martello Tower at Pontac the characters of the diabase and the rocks immediately associated with it are most interesting. Here, close in to the shore, can be seen the partial splitting-off and the entire isolation of a fragment, together with the subsequent softening and trailing-out which it undergoes, a process accompanied in greater or less degree by the absorption of its substance. This is referred to as the earlier brecciation. The texture of adjacent fragments varies from a fine-grained rock, with its constituents barely distinguishable by the naked eye, to a much coarser one in which the mottling of hornblende and felspar can be at once seen. In many cases the most clearly defined fragments show curved outlines with blunt projections, indicating that they were in a softened state during the intrusion of the more acid magma. Frequently the rock round them contains more hornblende than the vein proper, and scattered through this zone, which may be ½ inch wide, are numerous small fine-grained patches indistinguishable from the fragment. There can be no doubt that these represent portions which have escaped absorption.

In places the hornblendes which the more acid rock contains are rounded and granular, at others the mineral occurs in foliated flakes producing a gneissose appearance; while close at hand these may be replaced, sometimes in a patchy way, by another type of a long prismatic habit. These changes are, no doubt, due entirely to local conditions which arise in near proximity the one to the other. Thin sections show that the quartz present varies in quantity, but on the whole it is not common.

The felspars present some interesting features. With ordinary light the plagioclases which constitute the dominant felspar frequently exhibit in certain parts a slight difference in translucency and a distinct position of extinction between crossed nicols. The differentiated spaces form indented bays or isolated lakes in the felspar-crystal, which then has partly idiomorphic outlines turned towards them (fig. 1). These outlines correspond (as may be seen

Fig. 1.—*Plagioclase-crystal showing corroded spaces, and almost entirely surrounded by flakes of hornblende and mica, three or four of which are embedded in it* ($\times 38$).

best between crossed nicols) to part of the edge of a granule into an aggregate of which the original crystal is in process of being resolved. That this change has been facilitated in many cases by straining and fracture of the crystals prior to consolidation appears from the bending and disjointing which the plagioclase-twins frequently show. The extreme stage in the process of corrosion is reached when the substance penetrating the felspar, increasing in strength, wedges the latter apart and forms a felspathic base in

which grains or partly idiomorphic felspars lie scattered. These grains frequently polarize as distinct individuals. The extinctions of five or six crystals which are cut approximately perpendicular to 010 indicate albite or oligoclase. Neither twinning nor extinction is very regular. The investing felspar is clear, save for faint flecks of brown kaolin, and in many cases it is not easily distinguished with certainty from quartz. It appears to be usually orthoclase, but occasionally a resemblance to the cross-hatched structure of microcline is found. Sometimes quartz takes the place of the embedding felspar; it never occurs in definite grains, and on the whole is not common. Occasionally a crystal shows itself between crossed nicols to be built up of closely-packed polygonal grains, each polarizing at a slightly different angle from that of its neighbour, and in this case the clear replacing felspar is almost entirely absent.

The two remaining principal constituents are green hornblende and a mica, usually rather altered, brownish or green in colour. The mica is of late consolidation, and is characteristically embedded between the grains of felspar in irregular flakes. That its formation is subsequent to the breaking up of the felspar-crystals, as at Sorel Point, is thus apparent. A very strong resemblance exists between the changes which have taken place in the felspars of the rocks from that locality[1] and those just described.

An examination of the earlier stages of this process of reconstitution shows that solution has been effected with greatest facility parallel to the direction of the albite-twinning, but the blunt rectangles or even squares formed by the replacing felspar indicate that absorption has proceeded almost uniformly in every direction.

(2) Nature of the Earlier Intrusive Magma.

It is rather difficult to determine what the nature of the invading magma really was, but there can be no doubt that at the time of intrusion the constituents requisite for hornblende and mica were poorly represented or entirely absent, and that the silica-percentage was not high.

Sections cut from specimens which show little or no material derived from the older basic[2] rock through which the intruder passed present a structure sometimes like that just described, of which the corrosion of the felspars is the most striking feature. In others such corrosion is absent, and the slide consists of interlocking and mutually interfering felspars, with no quartz, a little hornblende, and presenting a gneissose appearance. These felspars are so opaque that it is difficult to determine the species, but they are for the most part a plagioclase. The hornblende, in the majority of cases, is probably derived by a process of absorption from the diabase. We may seek an explanation of these structures in the

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 437, figs. 1 & 2.

[2] That is, no augite and little or no hornblende or mica (derived as a product of hornblende with felspar).

supposition that differentiation of the magma resulted in the formation of a region from which ferro-magnesian constituents were almost entirely absent, but which contained those of felspars identical in composition with the species of the diabase or one slightly more acid. Another region might be formed in which, when it had crystallized, hornblende and mica would be absent, quartz present in small quantities, and the felspars would be an acid plagioclase and orthoclase. Movement in these parts of the magma would result probably in the intrusion into the larger body of diabase of either one of these varieties or of any mixture of them; and hence might arise the phenomena of corrosion and replacement seen in some of the slides. On this hypothesis the corroded plagioclases described in the foregoing section (p. 309) would belong for the most part, not to the diabase, but to a less basic rock which had been intruded into, and to some extent altered by, one of still less basic composition.

At the same time some of the appearances of fracture and corrosion may be due to movement during consolidation, and to variations in temperature and pressure attendant on intrusion, which caused part of the felspar-substance again to enter into solution.

(3) Phenomena attending the Earlier Acid Intrusion.

Having thus obtained some idea of the nature of the intruder, we may pass on to consider a few facts connected with its passage through the older rock.

A thin section cut across a junction (rather sharply defined in the specimen) shows a dark compact rock on one side, and a coarser, with conspicuous actinolitic hornblendes, representing the intruder, on the other. The passage from the former to the latter is more marked between crossed nicols than in ordinary light. It is made apparent by a sudden increase in the size of the felspars and of the hornblendes (no augite at all is found in this section), and by the presence of quartz wedged in between the other constituents. There is, however, a little quartz in the more basic rock. Long plagioclases in great number are found in the intruder, often embedded in a pale brown-red felspar which appears to be orthoclase: sometimes quartz takes the place of this orthoclase. Apatite is found in some quantity. The hornblendes are fairly idiomorphic; the pleochroism is of a straw-yellow colour with a slight tinge of green, to rather dark green with a brownish tinge. The usual length is $\frac{1}{5}$ inch, occasionally $\frac{2}{5}$ inch. The hornblendes of the more basic part (the rock intruded into) are granular, and accordingly seldom or never idiomorphic. In the centre of one, a little rusty-red ferruginous matter surrounded by an area of somewhat lighter colour represents probably the lingering traces of augite. In other sections quite clear augite-cores are found, but not commonly.

Field-evidence shows that this is not an intrusion of the ordinary type. The younger rock, that with actinolitic hornblendes at about 4 inches from the junction, contains a band, not very clearly

defined, of rounded speckly hornblendes with smaller ones between them, making the whole of this area rather dark in colour. To this succeeds a space characterized by larger but rounded hornblendes, which in turn passes into a fine-grained mottled rock not identical with the older one at the junction, but becoming closely similar and indeed identical with it 2 inches or so farther on. There is a slightly streaky look about this sometimes, as though the latter part of the above change were not quite uniform.

Locally at Le Nez the intrusive or veining rock becomes much coarser. The quartz is not conspicuous to the naked eye, so that two minerals only appear, namely, hornblende commonly in prisms which are sometimes $1\frac{3}{4}$ inches long, at others in irregular patches; and a matrix of yellowish-white felspar.[1] A thin section shows some

Fig. 2.—*Intrusive actinolitic rock from near Le Nez, Jersey (about $\frac{2}{3}$ nat. size).*

orthoclase, late in consolidation like the quartz, wedged in between the other constituents. The difference in the degree of coarseness is due to the hornblende, rather than to an increase in the size of the plagioclases. The long prismatic hornblendes frequently contain a felspar-centre, and in places crystals of the latter mineral project into the former in an ophitic manner. This rock becomes finer in grain through the rather rapid diminution in size of the

[1] Prof. A. de Lapparent regards this rock as a mere variation of the 'epidiorite,' and he describes it as either a quartz-diorite or a hornblende-granite, according to minor variations in mineral composition. The plagioclase he defines as oligoclase. See 'Les Roches éruptives de l'Ile de Jersey' Ann. Soc. Sci. Brux. vol. xvi, pt. ii (1892) p. 226 [sep. cops. p. 7].

hornblendes, and is finally seen to cut and break up the darker older rock as above described (p. 312). The whole passage from coarse to quite fine takes place well within 6 yards, but the very coarse variety appears in patches and clot-like streaks. In one place a shadowy band can be traced on the weathered surface of the rock for 11 or 12 yards, composed of ill-defined patches, which represent fragments in more or less complete stages of dissolution. This rock, variable in composition and non-homogeneous in origin, passes into a rather finely-mottled black-and-white rock with numerous large hornblendes irregularly spread through it. In some places the passage is fairly regular and gradual, at others more sharply defined. Specimens may be found, in which the coarse intergrowth of hornblende and felspar forms bands separated the one from the other by much more finely-mottled material; others contain indefinite patches of the same kind.

This finely-mottled rock differs from the coarse rock with the elongated hornblendes in one or two important points. In the former the hornblende either is a matrix for the earlier consolidated felspar, or occurs in grains seldom if ever idiomorphic. Paler and fibrous patches suggest original augite. There is little to distinguish these sections from those of a diabase. Although a few grains of quartz are found, and also a little orthoclase as usual wedged in between the other constituents, the conclusion is suggested that these are fragments of the diabase which have escaped dissolution. The traces of acid minerals might be expected, when the changes which the surrounding rock has undergone are considered.

(4) The Granite or Later Acid Intrusion.

The granite of the Eastern District forms the more outlying crags of Grève d'Azette and St. Clement's Bay. It is a pinkish or pale flesh-coloured rock of medium grain, containing orthoclases nearly $\frac{1}{4}$ inch long, and occasionally twice that size. Quartz is present in some quantity; hornblende and mica are decidedly scarce. A thin section shows the dominant constituent to be orthoclase, slightly kaolinized and exhibiting the usual microperthitic intergrowth; quartz, in groups of grains without a granophyric relation to the felspar; and a little albite, or an altered plagioclase. There are a few small flakes of a brownish-green, rather fibrous mica. The rock shows a close resemblance to the earlier porphyritic intrusion of Sorel Point; its specific gravity, as determined by a Walker's balance, is the same: namely, 2·606.

The incorporation of diabase-fragments by this granite is quite local, and it is often far from easy to decide whether any one instance is due to the intrusion of this rock or to that which produced the earlier brecciation described on p. 308. With the aid of the microscope, however, much of this difficulty disappears, thanks in great measure to resemblances shown to the rocks of Sorel Point. Here, as there, we have unequivocal evidence of change amounting

to total reconstitution. The testimony even of hand-specimens is clear. Sometimes we find black fragments included in the granite; at others dark shapeless patches embodied in the surrounding rock; finally, these completely disseminated among the other constituents. Thin sections show that these resemblances are carried into even the smaller details of rock-structure. Here are the same small scattered flakes of mica and hornblende, the same meshwork of long felspars, the same infilling quartz, the same needles of sillimanite. Minor points of difference do indeed exist: the mica is perhaps often more fibrous in character; the granular hornblende is wanting in great measure; the long rectangles of hæmatite are absent. The plagioclases are often zoned, and the extinction of the central parts frequently indicates labradorite. In one place we catch sight of fragments of diabase, less completely disintegrated, where lingering traces of augite yet remain.

A well-defined dyke, some 12 or 14 inches wide, cutting sharply across a gneissose dyke belonging to the earlier brecciation, has so close a relation to the granite (it contains both hornblende and mica and some black fragments) that it is considered part of that rock, although its point of origin could not be traced in the field.

Accordingly we may conclude that the main body of the intrusive granite was posterior to the intrusion which produced the various hornblende-rocks connected with the diabase, though it is not suggested that the difference of age was considerable. On the contrary, at one point on the south side of Le Nez the rock producing the earlier brecciation becomes much coarser, contains both orthoclase and quartz, and is separable only with some difficulty from the later granite. Comparing a series of sections, the latter is seen to possess considerably more quartz, the orthoclase is characterized by a microperthitic intergrowth, and, where mixture with the basic rock has taken place, a texture and general structure are preserved which indicate a true granite. Usually more mica is present in such slices. Some microperthitic orthoclase is found in the Le Nez series embedding the other constituents, and corroding the plagioclases, seeming to herald the approach of the next intrusion, that of the true granite.

The practical identity in the mixed rocks from the south and north of the island shows, I think conclusively, that not only was the intrusion of magma the same in both cases, but also the physical conditions attendant on its intrusion were at least similar over this comparatively large area. The products, however, of the earlier brecciation, as I have called it, confined to Le Nez and its neighbourhood, are so strikingly different that the operative causes can scarcely have been the same.

(5) Comparison with Rocks in Guernsey.

The fine-grained black rock with granular hornblendes mentioned on p. 311 differs from a diabase in important respects. The hornblende is no doubt original for the most part, but the earlier

crystallization of the felspar and an occasional tendency to penetrate the hornblende-grains recall slightly the ophitic structure of a diabase. In the same way the augite-cores, occasionally found in the larger hornblende-individuals, suggest some relation to such a rock. A very close resemblance to this hornblende-plagioclase rock exists in the fine-grained black dykes which cut the hornblende-gabbro of the eastern coast of Guernsey.[1] Without entering into details at the present time, it may not be out of place to enumerate a few points of resemblance between the rocks of the two islands.

Omitting the gneiss of Guernsey, we find a dolerite or gabbro to be the oldest rock in both areas. In the south-eastern corner of Jersey, as described above, a dioritic rock is associated with the diabase; in Guernsey, dykes very similar to this cut the hornblende-gabbro, which is itself subject to great mineral variations. The field-evidence indicates that these dykes were derived from the same source as the gabbro; in Jersey the two rocks are closely connected, but the one is not seen to cut the other. In both islands the next intrusion was, when solid, a felspathic rock, containing little or no quartz, hornblende, or mica. In Jersey this intrusion resulted in the production of a new rock, by a process of mixture which is characterized by the development of coarse actinolitic hornblende; in Guernsey, rocks occur with the same peculiar elongated hornblendes, produced apparently by a closely analogous sequence of events. Putting aside the diorites of Northern Guernsey, an intrusion of a granite-magma succeeded the rocks mentioned, as in the neighbouring island. In both Jersey and Guernsey this intrusion resulted in the softening and local melting of the rocks intruded into.

In seeking for an explanation, we may adopt the hypothesis that the differentiation of the magma formed regions always poor in ferromagnesian minerals which became progressively more acid; and we may suppose that between the body of basic material now represented by the diabase and those more acid regions a magma of a dioritic composition was present, forming the fine-grained granular hornblende-rock referred to above. This probably passed little by little into the augite-bearing rock.

III. The Western District.

(1) General Characters of the Acid Intrusion.

The intrusive rock of St. Elizabeth's Castle is a fine-grained red aplite, with a very few porphyritic felspars, about $\frac{1}{3}$ inch long. In a thin section a considerable quantity of quartz forming angular grains may be seen.

An approach to a granophyric structure occurs when three or four quartz-grains embedded in felspar polarize together. The brownish

[1] See the paper by the Rev. E. Hill, with an Appendix on the Microscopic Structure by Prof. T. G. Bonney, Quart. Journ. Geol. Soc. vol. xl (1884) p. 404.

felspar, forming a kind of network with the quartz, is principally orthoclase with some microperthite. A zone of brownish unstriped felspar usually surrounds the larger plagioclases. The section contains a few flakes of greenish mica in various stages of decomposition, and a rare zircon-crystal. This rock has forced its way into a fine-grained, greyish or greenish, non-porphyritic diabase, often shattering it to a wonderful extent. A thin section cut from a specimen of the diabase, purposely chosen from a point where it might be supposed to have escaped any alteration by the aplite, affords an excellent example of the extent to which permeation by the acid magma has taken place. The older rock in the hand-specimen shows no sign of quartz; it is compact, with the characteristic weathering and fracture of a diabase. The microscope, however, reveals the presence of a considerable quantity of quartz, in grains, often forming micropegmatite with an acid felspar. Recognizable augite in some quantity is found in the rest of the section. No clearly-defined line of demarcation exists between the acid and basic parts. On the contrary, the acid minerals have insinuated themselves between the constituents of the diabase, and, although often conspicuous, are sometimes only distinguishable with difficulty. The quartz-grains do not exceed ·036 inch in length; the average length is about ·016 inch.

The presence of this mineral in so homogeneous-looking a rock is not easy to understand, and I am indebted to Prof. Bonney for the suggestion that the siliceous and felspathic substances have been conveyed into the diabase in the form of an aqueous solution rather than by an injection, pure and simple, of the acid magma.

The recent work of M. Lacroix has an important bearing on this point. In his paper on 'Le Granite des Pyrénées et ses Phénomènes de Contact' he enunciates the theory to which his observations lend support in the following terms:—'Les phénomènes de contact des roches éruptives sont le résultat de la transformation d'une roche préexistante, apportant sa caractéristique personnelle, sous l'influence d'agents minéralisateurs, le plus généralement accompagnés d'éléments volatils ou solubles qui, en se fixant sur la roche modifiée, en transforment plus ou moins complètement la composition chimique.'[1]

The zone of altered rock in contact with the intrusive granite furnishes an example of the action to which he refers (*op. cit.* p. 8). This zone is characterized by the presence of granular felspar which the older rock (schists, quartzites, etc.) may acquire by one of two methods, or by both of these acting together:—(i) by simple injection of the acid magma, or (ii) by 'imbibition,' when microscopical examination is necessary to establish the phenomena. The second method he considers to be carried out by means of hydrothermal agents, or, in general, by 'agents minéralisateurs.'

[1] Bull. Serv. Carte Géol. France, No. 64, vol. x (1898–99) p. 48. See also Michel-Lévy 'Sur la Classification des Magmas des Roches éruptives,' Bull. Soc. Géol. France, ser. 3, vol. xxv (1897) p. 370; & Lacroix, Bull. Serv. Carte Géol. France, No. 42, vol. vi (1894–95).

The presence of micropegmatite is common in the altered rocks from St. Elizabeth's Castle and near Fort Regent, as Prof. de Lapparent has pointed out.[1] He clearly recognizes that the intimate penetration of the 'epidiorite' (diabase) by the acid magma has resulted in the absorption of material by the intruder, and that we have produced 'une roche mixte, à la fois verte et rosée, où le quartz pegmatoïde court comme une trame au milieu des éléments encore reconnaissables de l'épidiorite.' The process of alteration in the diabase so closely resembles other instances from Jersey that a detailed description would be mere repetition. There is the same gradual increase in the size and number of the acid patches, and it is interesting to note the gradual isolation in those of the felspars of the diabase. They frequently become coated over with a layer of acid felspar, or of this and quartz in more or less micropegmatitic contact. The possible occurrence of allanite in one or two slides is of interest. This mineral has been recorded from these rocks by Prof. de Lapparent.[2]

The field-evidence is completely in accord with the microscopic. A gradual change can be traced from the red unadulterated granite, poor in the dark minerals, to a reddish-yellow rock rich in both hornblende and mica, and crowded with the dark felspars of the diabase. Here and there occurs a less completely disintegrated fragment. Often such dark fragments are scattered in a canary-yellow rock speckled plentifully with the dark minerals. As the latter increase in quantity it becomes gradually more difficult to distinguish the fragments, until the rock appears to be neither 'diorite' nor granite. This may be explained by the absorption and impregnation of the diabase in various degrees by an acid magma. The phenomena of Havre des Pas are essentially similar. The boundary of the red and dark rocks could be traced sometimes, but at others the blur of colour round the junction was very marked.

A slide cut from a dark dioritic rock below Fort Regent is worthy of brief mention. It was presumably once a diabase, but a thin section shows it to contain a considerable quantity of quartz and some pale acid felspars, usually added zonally to the opaque lath-shaped felspars of the older rock. No augite is found, but green hornblende is frequent in a granular form, recalling the glomeruli mentioned in a former paper.[3] Irregular flakes of a rather fibrous brown mica and flakes of magnetite are associated with the hornblende-grains. Frequently the latter are not more than ·012 inch in diameter, and instead of being closely packed together are dispersed, favouring the acid felspar in their distribution. The colourless acicular crystals referred to sillimanite are not uncommon.

The intrusive aplite of St. Elizabeth's Castle and of the shore under Fort Regent is in all probability the same as the aplitic

[1] 'Les Roches éruptives de l'Ile de Jersey,' Ann. Soc. Sci. Brux. vol. xvi, t. ii (1892) p. 233 [sep. cops. p. 14].

[2] Ann. Soc. Sci. Brux. vol. xvi, pt. ii (1892) p. 234 [sep. cops. p. 15].

[3] Quart. Journ. Geol. Soc. vol. lv (1899) p. 441 and reference given there.

intrusion which followed the porphyritic granite at Sorel Point. Differences exist between them, but they are of a minor character. Thus, the southern rocks contain micropegmatite; in the northern the intergrowth of quartz and felspar, where it occurs, is coarser and of a less pronounced character. The southern rocks often contain microporphyritic crystals of plagioclase; in the northern similar crystals, though frequent, escape notice among their coarser-grained surroundings, also a considerable quantity of plagioclase is intergrown with orthoclase. Both rocks, equally, are deficient in hornblende and mica. The differences, then, on the whole seem to be due rather to dissimilar conditions during consolidation than to variety of composition. The specific gravity is the same, namely, 2·59.

(2) Relation of the Intrusive Acid Rock of the Western to that of the Eastern District.

It remains to be seen what relation the aplite of St. Elizabeth's Castle bears to the granite of Grève d'Azette and St. Clement's Bay. The westernmost limit at which the latter rock is found is at the Bathing Pool between Le Dicq and Havre des Pas. On the western side of the pool is the fine-grained red aplite; on the eastern is the granite, porphyritic, coarse, and enclosing numerous dark fragments in various stages of absorption. The pool appears to cover the junction of the two rocks, but a few crags outcropping on the southern side help us in forming a conclusion as to their relations. These crags are clearly connected with the porphyritic coarse granite, but vary considerably in composition and grain: an inconstancy that is largely due—as may be clearly seen when on the spot—to absorption of basic material. Crossing a short strip of sand, we come to the fine-grained aplite, which here and there shows irregular streaks and veins containing felspars quite $\frac{3}{8}$ inch long, with some quantity of the dark minerals. This weathers in a granular manner; in other words, it presents a great resemblance to the granitic rock in the immediate neighbourhood.

On the eastern side of the pool the coarse granite is cut by dykes of a red aplite, indistinguishable from that of Havre des Pas and St. Elizabeth's Castle; and these, as thin sections show, contain occasionally some amount of basic material. Accordingly we may conclude that the fine-grained aplite is younger than the porphyritic granite, but that the difference in age is probably not great.

IV. Conclusions.

Taking the rocks in order of age, we have:—

(i) Firstly, a diabase, no doubt identical with that from the north side of the island; and associated with this, a rock composed essentially of granular hornblendes (differing from those of the

diabase) and plagioclase, but occasionally containing augite. The two rocks are probably closely related.

(ii) These were brecciated by a more acid magma, represented by a rock containing plagioclase and some orthoclase, but poor in quartz, hornblende, and mica, with the result that considerable mixing took place.

(iii) The result of this mixing was to produce a rock characterized sometimes by a gneissose structure, at others by elongated hornblendes, occasionally of large size. Mica is conspicuously absent.

(iv) A further intrusion of a still more acid magma followed, which solidified as a granite very closely resembling the earlier porphyritic intrusion of Sorel Point.

(v) This produced locally, by mixture, rocks which may be said to be distinguished by the presence of biotite, quartz, and the characteristic orthoclase of the granite.

(vi) To these succeeded another intrusion of the acid magma, forming a rock redder in colour, finer in grain, sometimes micropegmatitic, and closely related to an aplite. This is typically developed in the Western District round St. Elizabeth's Castle, and is correlated with the second intrusion of the acid magma at Sorel Point.

(vii) A process of absorption and mixture again resulted; and the penetration of the diabase by quartz and felspar (carried often to an unexpected degree) leads me to suggest the possibility of those minerals being introduced by hydrothermal agencies.

(viii) Evidence in the field and with the microscope is brought forward to show that the difference in age between these various rocks was probably not great, and it is accordingly suggested that they may have been differentiated from a single magma.

So far as it goes, the evidence afforded by the rocks of Guernsey bears out the sequence of intrusion described in this paper.

Finally, I wish to acknowledge the help afforded by Prof. Bonney, not only in study with the microscope, but also in the theoretical questions which arose during the investigation.

19. *The* Rocks *of* La Saline (Northern Jersey). By John Parkinson, Esq., F.G.S. (Read March 7th, 1900.)

The rocks of La Saline, an indentation of the larger St. John's Bay, resemble very closely those from Sorel Point, a little less than a mile to the west. Around the latter headland we find that a porphyritic granite has forced its way into a diabase, shattering and breaking it up, softening and locally melting it. Hence changes can be readily traced in the acid magma, which is rendered basic, and in the diabase which is impregnated by it. M. Noury mentions and maps[1] an outcrop of 'diorite' at one point in the bay of La Saline and surrounded by granite, but clear evidences of intrusion are wanting.

In a quarry on the cliff-top, and cropping out on a sloping path which leads towards the eastern end of the bay, is a rather coarse granite containing some quantity both of hornblende and mica, a fair amount of quartz, and large flesh-coloured orthoclases sometimes $\frac{4}{5}$ inch long. At the eastern end, and forming the crags on the shore, occurs a redder rock, less markedly porphyritic and inclining as a rule towards an aplite, though occasionally some quantity of black mica is present; its specific gravity is 2·60. At Sorel Point[2] two distinct intrusions of the acid magma are found: an earlier, porphyritic, which has melted and partly incorporated fragments of the diabase; and a later, non-porphyritic aplite which took the same course as did the first, but without its effect on the diabase. These two have kept themselves distinct, though intimately associated with each other. At La Saline both field and microscopic examination suggest a passage, though perhaps a rapid one, between the two rocks described above, which show a general analogy to those from Sorel Point. Specimens distinct enough can be easily found, but the study of a series tends to bridge the gap.

Both contain large quartz-grains without a granophyric relation to the felspars, and orthoclase with a microperthitic intergrowth. The rock of the quarry possesses some quantity of free plagioclase, but this is not absent from the red rock of the shore, where, however, it is for the most part intergrown with orthoclase. Not unfrequently the latter constituent is porphyritic. There is always a little black mica, occasionally a considerable quantity, and herein lies the interest. At one or two points just below high-water mark one finds the red aplitic rock looking as though it had been irregularly peppered, a peculiarity due to the presence of irregular and ill-defined patches containing much black mica. This peppered appearance catches the eye on the weathered surface of the rock, and the patches join one with another in a kind of rough network. The rock is rather more finely grained than usual. Close by, the quantity of

[1] 'Géologie de Jersey' 1886, p. 22.
[2] Quart. Journ. Geol. Soc. vol. lv (1899) p. 430.

mica makes the rock appear quite dark, but here it is more evenly distributed. This is also distinctly fine-grained. Again in a few yards the rock is exposed both coarse and porphyritic, but still containing some quantity of mica. Some 5 or 6 yards from the peppered rock is a very irregular dark patch, measuring roughly 24 by 20 inches, and containing much mica. A thin section shows this to exist in well-formed flakes, commonly ·03 inch across, dark straw-yellow in colour, with very strong absorption. There are also idiomorphic hornblendes now greatly altered, but retaining crystal-outlines; and rather dusty quartz, like that in the surrounding rock, is abundant. The felspars consist of orthoclase with microperthitic intergrowth, and some quantity of plagioclase having low extinction-angles. The mica, in appearance and mode of occurrence, does not differ from that of the rocks close by.

This patch, inclusion, or segregation has no very distinct edges, but a conspicuous shading-off of the dark minerals into the surrounding rock is not seen. Outlying patches are found close by, apparently separate from the main mass.

The evidence afforded by this group of rocks alone might perhaps point to a certain irregularity of composition in an acid magma, and some segregation of the more basic materials during consolidation. But they do not stand alone: on the upper part of the cliff at the western end of the Bay, *i.e.* at that nearest Sorel Point, a fine-grained, rather dark rock appears above the surface in outcrops mingled with others of a more granitic texture. (Some of these are possibly the 'diorite' mentioned by M. Noury.) These greatly strengthen the suspicion, as to the true origin of the mica in the rocks of the shore, which the nearness of the mixed and altered rocks of Sorel Point would of itself have raised. There can be no doubt that in this corner of the Bay granite occurs, containing material absorbed from a diabase (dolerite), probably also diabase impregnated by an acid magma. Under the microscope we find remnants of greatly altered diabase, whose hornblendes are illshapen and associated with biotite teased out into an embedding matrix of quartz-grains and felspars, for the most part orthoclase, testifying clearly to the non-homogeneous nature of the rock. Through the more acid meshwork —which contains large orthoclases—multitudes of colourless acicular crystals, referred to sillimanite, are scattered. Not included in the section, but common in the rock, are groups of quartz-grains surrounded by narrow hornblende-rings. These are also a feature in the similar rocks from Sorel Point.

A fragment of a fine-grained, non-porphyritic, speckled grey-and-white rock, measuring 9 by $4\frac{1}{2}$ inches, which is included in the coarse aplitic rock of the shore below, may possibly be allied to such mixed rocks in its mode of origin. In a thin section are seen numerous lath-shaped opaque felspars surrounded by clearer zones, apparently of an acid plagioclase, a few irregular crystals of orthoclase, flakes of brown mica and dark-green hornblende, and some quantity of quartz. The last-named occurs sometimes in grains, which in one case

measure ·04 inch across, but more usually the quartz is late in consolidation and embeds the other constituents. Analogy with examples from both the north and south of the island, of less doubtful origin, suggests that here is a portion of diabase which has been permeated and altered by an acid magma, and then included as a fragment in the aplite.

As a general conclusion, it is submitted that the mica of the aplite-rock,[1] and therefore, by implication, that of the porphyritic granite of the quarry, is of foreign origin; and that it is a result of the melting and incorporation of fragments of diabase during the passage of the acid magma to its present position.

One point of considerable interest remains. On the shore at the western end of the Bay the rapid change, from a coarse rock containing a considerable quantity of quartz and closely related to the usual aplite, into one in which quartz is conspicuously absent may be traced. The disappearance of this constituent is so sudden that one may put one's finger on the spot where it dies out. The quartz-bearing rock contains mica, possibly some hornblende, now replaced to a great extent by a green chlorite, and large red felspars, often $\frac{4}{5}$ inch long, with intergrown plagioclase. The quartz is found in grains ·16 inch or so across. Nor is free plagioclase wanting. The slide does not differ in any essential point from those previously described. There is on the whole more plagioclase in the quartzless rock,[2] sections approximately normal to 010 indicating albite and oligoclase. Wedged in between the felspars is some quantity of a soft black substance, which a thin section shows to be chlorite. It has a finely mottled appearance in ordinary light, a speckled one between crossed nicols. This substance, now represented by the chlorite, was clearly the last constituent to consolidate, since it embeds the smaller felspars, extends in tongues between the larger, and in places has split and forced its way into them. With it are a little white mica and some opacite. In addition to the fracturing there is evidence of some corrosion; but the felspars are not zoned. The rock is miarolitic.

To give an explanation of its history is far from easy, and the following one is put forward with some hesitation. In certain thin sections from the neighbourhood the mica is seen to form flakes of very irregular outline, embedding the crystals of felspar, and in places enclosing them in a manner closely resembling that which distinguishes the chlorite. Similarly, mica late in consolidation characterizes many of the allied rocks from Southern Jersey. It is, therefore, quite possible that the chlorite has replaced this mineral; while the propinquity of mixed rocks arising from the alteration of a dolerite by an acid magma strongly suggests that this mica is, in a sense, of secondary origin. In the present instance the almost entire absence of quartz in the chlorite-bearing specimen does not

[1] See the Rev. E. Hill & Prof. T. G. Bonney's paper on the 'Hornblende-schists, Gneisses, etc. of Sark' Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 132.

[2] Two grains of quartz appear in one section, and therefore the term 'quartzless' is not strictly applicable.

favour the supposition of a simple intrusion, since in all the altered rocks quartz accompanies the change in the dolerite. The regular line of division between the quartz-bearing and quartzless rocks points in the same direction. Accordingly we may suppose that in an early stage in the process, but after the porphyritic orthoclases had formed, an acid magma succeeded in softening and melting a mass of dolerite: the augite *plus* alumino-alkaline constituents from the felspar produced a mica; while the plagioclase was entirely dissolved. Specimens may be found from both the north and south of the island in which basic elements (hornblende and mica) largely predominate, but which contain numerous orthoclases embedded in them. There is therefore less difficulty in concluding that, after the alteration of the basic rock had been effected, a process of segregation drew together the porphyritic orthoclases, plagioclase, mica, and possibly some hornblende. Movement of the whole mass might follow, and the quartz-bearing and quartzless parts would drag along together, fracturing the felspars and producing the impression, after solidification, of a regular passage from one rock to another.

J. Arthur Phillips, in his paper on 'Concretionary Patches and Fragments of other Rocks contained in Granite,'[1] defined the former as being the result of an abnormal arrangement of the minerals constituting the granite itself; fine-grained; containing a proportion of triclinic felspar often greater than in the rock which encloses them; and porphyritic, such porphyritic crystals being those of the surrounding rock. These characters, he considered, differentiate concretions from fragments.

The study of rocks such as those described in the preceding notes suggests the possibility of another hypothesis. We see that a fragment of diabase included in granite does not remain necessarily of a mineralogical composition identical with that which it had before the intrusion of the acid magma, but that sometimes the change is such as to result in the production of a type of rock bearing not the slightest resemblance to the original. The addition of quartz and orthoclase, the development of biotite and idiomorphic hornblende, and the not infrequent introduction of porphyritic crystals from the surrounding magma, completely alter the nature of the fragment. The difficulty of determining satisfactorily remnants of basic plagioclase, even if such exist, frequently destroys any ground on which suspicion might legitimately rest. In the absence of other evidence there is, perhaps, no option but to conclude that the basic patch in question is a concretion or segregation produced during consolidation.

Additional evidence, however, is available sometimes, and we are enabled, by working from the complete to the incomplete, to find a cause for structures the explanation of which would otherwise remain inconclusive and unsatisfactory. Taking the rocks round Sorel Point as a basis upon which to work, an important clue to

[1] Quart. Journ. Geol. Soc. vol. xxxvi (1880) p. 1.

the history of those from La Saline can be obtained from evidence which in itself is anything but clear. It has been pointed out in the preceding pages that reconstitution of the minerals of included fragments takes place by the introduction of constituents from the involving magma; that the dark patches found in granites may result from the complete alteration of such inclusions; and that, by the dissemination of the minerals of the fragmentary patches thus produced, new constituents may be added to the intruding rock.

In conclusion I wish gratefully to acknowledge the help that Prof. Bonney has afforded me in the preparation of these notes.

Discussion (on the two foregoing Papers).

Prof. Sollas said that he recognized the great value of the conclusions to which the Author had been led. The statement that successive intrusions cannot be separated one from the other by hard-and-fast lines suggested that the district was a somewhat exceptional one. In most cases when a passage appeared to exist between different kinds of rocks, even when these were as closely allied as a granite-porphyry and a quartz-porphyry, patient examination would usually reveal a sharp line of demarcation between them. As regards differentiation, the existence of 'mixture' explained many cases, supposed to be due to this hypothetical process, in another manner; and the statement that the rocks described were intruded in an order of increasing acidity seemed to gain little from a translation into hypothetical terms. It must not be overlooked that while in some districts the order of eruption was one of increasing acidity, in others it was, on the contrary, one of increasing basicity.

As regards the solution of a dolerite by granite (suggested in the paper on La Saline), it might be observed that the consolidation-point of a granite was certainly lower than the fusion-point of a basalt; if, therefore, the latter has been dissolved by the former, the solvent (granite) must have been in a state of superfusion, and its differentiation could scarcely be explained as a result of progressing crystallization.

The President also spoke.

Prof. Bonney, in the absence of the Author, replied that the latter's remarks on the difficulty of distinguishing cases of intrusion applied to this particular locality, where it certainly existed. He had always believed that basalt was a rock that was easily fused, and was not prepared to accept Prof. Sollas's statement about it and granite. The idea of differentiation played a very subordinate part in the paper, and was only put forward as an hypothesis. At any rate, it seemed not inconsistent with the facts.

20. FURTHER EVIDENCE *of the* SKELETON *of* *EURYCARPUS OWENI*. By Prof. H. G. SEELEY, F.R.S., F.L.S., V.P.G.S. (Read February 21st, 1900.)

[PLATE XXI.]

IN 1876[1] Sir Richard Owen figured a fossil from the Sneeuwberg which was referred to a young or small Dicynodont reptile, and described as showing impressions of the neural arches and ribs, of cervical and dorsal vertebræ, and of bones of the left fore-limb. Eight ribs are shown and described. It is stated that 'the distal end of the humerus is much expanded; the radius and ulna are distinct and in a prone position; the palm of the fore-paw has impressed the surface of the slab.' The hand is briefly described, and the author remarks upon the agreement with the mammalian formula of phalanges, seen in its five digits. This underside of the hand was figured again in 1880[2] in illustration of the foot of *Platypodosaurus*. Owen mentions no evidence of the Dicynodont characters of the specimen, though it was doubtfully referred to *Dicynodon*. It was afterwards named *Eurycarpus Oweni* and more carefully figured in 1889.[3] The original specimen was presented to the British Museum in 1872 by Mr. Thomas Bain, through Sir Henry Barkly, who was then Governor of Cape Colony.

One of my objects in visiting South Africa in 1889 was to recover, if possible, the remainder of this specimen, which was the only skeleton then known with the limbs in natural association with the vertebral column. A visit to Graaf Reinet, however, was not possible. But I ascertained that the skull was found with the complete skeleton, and that a short memorandum on its characters was made by Mr. Thomas Bain on finding the fossil. The manuscript which Mr. Bain forwarded with the specimen has been preserved in the Natural History Museum; the document is important, and is here transcribed, with a photographic reproduction (fig. 1, p. 326) of the rough sketch which it includes:—

'Skeleton of a *Dicynodon* found in the Sneeuwberg, about 24 miles from Graaf Reinet. It is lying on its back, as can be seen from the roots of the teeth. The specimen sent fits on to the right arm. It is the only perfect impression of a paddle or hand yet found of the *Dicynodon*; I speak of course of those found by my late father, Dr. Atherstone, and myself. Therefore it may be worth preserving. It is likewise rare on account of the shape of the head (big-nosed), a shape seldom found among the *Dicynodon* species. The tail is buried under the projecting slab B, which could easily be knocked off and exposed; I have marked the spot in the event of His Excellency wishing to have it taken out. The skeleton is 2 feet 4 inches long, exclusive of its tail. At the same place where it was found I discovered numerous other fossil remains, but all too large to bring away, and they required some time to be disinterred.

'10th August, 1872. THOS. BAIN.'

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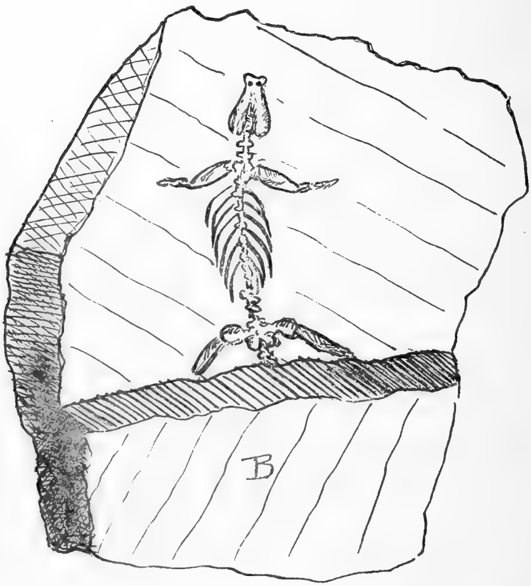
[1] Catal. Foss. Rept. S. Africa, pl. lii.
[2] Quart. Journ. Geol. Soc. vol. xxxvi, pl. xvii, fig. 5, p. 424.
[3] Phil. Trans. Roy. Soc. vol. clxxx (B) pl. xviii.

Mr. Bain wrote to me that he had no doubt that his sketch and my figure of *Eurycarpus* were both made from the same skeleton. The remainder of Mr. Bain's specimen was left in the rock and lost. The counterpart slab was in the possession of a Boer; and one half of that slab (without the head) eventually passed into the possession of the Rev. Charles Murray, of Graaf Reinet. That gentleman had the kindness to send me the specimen.[1] It shows the ventral aspect of the vertebræ, ribs, and limb-bones of which the dorsal aspect is already known.

Fig. 1.—*Photographic reproduction of Bain's sketch of the skeleton of* Eurycarpus Oweni.



An impression of the cavities left by the bones in this second slab was taken for me in the Natural History Museum. The two slabs were then fitted together, and plaster of Paris was run in between them, so as to show the upper and under surfaces and forms of the larger limb-bones and vertebræ.

The missing parts of the animal may be estimated from Mr. Bain's statement that the visible skeleton was 2 feet 4 inches long. The remains on this slab measure 1 foot $9\frac{1}{2}$ inches, showing that the skull and other parts which are lost could not have measured more than $6\frac{1}{2}$ inches in length.

No minute accuracy can be claimed for Mr. Bain's sketch. Its

[1] With it he sent a large fish, apparently a species of *Atherstonia*, which I presented to the Natural History Museum.

value consists in indicating the form and size of the head, which is a little less than a quarter of the length of the drawing; and thus agrees with the measurement of the Murray specimen, within a tenth of an inch.

The shape of the head as drawn was previously unknown. The discoverer differentiated it by means of the expanded form of the nose. This character was then and is still unknown in the genus *Dicynodon*. It is found to some extent in all Theriodontia, although the transverse constriction behind the canine teeth is more marked in Gomphodontia than in other Theriodonts. There is no direct evidence that the skull possessed Theriodont dentition, but the molar teeth might be hidden, and the sketch may imply that the roots of the canine teeth are seen in the lower jaw (fig. 1). The only group of Theriodonts known from the *Dicynodon*-beds is the Lycosauria; and it is probable that *Eurycarpus* may be referred to that group. A peculiar feature of the sketch is the concave anterior extremity of the nose.

The Vertebral Column. (Pl. XXI, *v*.)

The vertebræ are mostly in close order, with only very small displacements in their continuity. There may have been seven cervical vertebræ. Six appear to be indicated in Mr. Bain's original slab, by the short strong neural spines, which are not unlike those seen in *Tropidostoma Dunni*. The forms of the cervical vertebræ are not shown.

There are eleven dorsal vertebræ which support long ribs. They are succeeded by five vertebræ with short ribs. The hindermost of these terminates $1\frac{1}{2}$ inches in advance of the head of the femur. The total length of this part of the vertebral column, comprising fourteen vertebræ, is 16 inches. According to Mr. Bain's memorandum this would leave $3\frac{1}{2}$ inches for the sacrum and early caudal vertebræ which he indicated. This suggests a short sacrum, with not more than two or three vertebræ.

The depth from the summit of the neural arch to the base of the centrum is $1\frac{1}{2}$ inches, with but little variation down the length of the dorsal region; and this is in harmony with the skeletons already known of Anomodonts, such as *Cynognathus, Deuterosaurus, Procolophon*, and *Pareiasaurus*.

The front of the centrum appears to be a little wider than the back. The greatest width of an early dorsal vertebra in front is $\frac{9}{10}$ inch measured over the neural arch. The front margin of the articular surface of the centrum is a little thicker than the hinder margin. The articular faces of the centra are flattened or very slightly concave, but they are very imperfectly exposed. The length of the ventral surface of the dorsal vertebræ is $\frac{6}{10}$ inch in the front part of the back, but in its lower part they are slightly longer. The inferior margins of eight dorsal vertebræ are clearly seen, and they show no indication of intercentral ossifications such as have been described in *Cynognathus* and *Pareiasaurus*.

The external surface of each centrum is concave from front to back and rounded from above downward, with moderately elevated rounded articular margins, which are rather wider in the early dorsal than in the later dorsal vertebræ, but much narrower than the neural arches.

The Ribs. (Pl. XXI, *r*.)

As the ribs are preserved they extend in a semiovate contour, which was 12 inches long and about 8 inches wide below the middle of the back. As in many vertebrates, the ribs indicate depth in the region of the lungs, with increasing width in the lower part of the back. There is no indication of sternal or of abdominal ribs.

The anterior dorsal ribs are very imperfectly displayed at their proximal ends; but the distal ends of the first six or eight are so curved as to cross some of the later ribs transversely resting upon their undersides. The under surfaces of the ribs are rounded, with the anterior margin compressed and widened and defined by an inferior groove, like that seen in *Pareiasaurus*. There is no evidence whether the compression is also seen on the posterior margin. The ribs are compressed from above downward towards the free end. Near the proximal articulation each is also compressed from front to back. The rib terminates proximally in an expanded disc, which articulates low down on the anterior half of the side of the centrum. No tubercular attachment of the rib to the neural arch is seen. There is no evidence of articulation between the bodies of the vertebræ. In the genus *Herpetocheirus*, there is no trace of a tubercle in any of the ribs preserved. The articulation appears to be not unlike that found in *Microgomphodon*,[1] but *Eurycarpus* shows no trace of the uncinate process to the rib which Gomphodontia and Cynodontia share with some Labyrinthodonts such as *Eucheirosaurus*.

The Shoulder-girdle.

The bone in Mr. Bain's slab which I had doubtfully regarded as a scapula (or interclavicle) is proved by my new specimen to be so. Its articular surface for the humerus is seen a little in advance of the head of that bone. The scapula (Pl. XXI, *S*) lies laterally between the neural arches of the vertebræ and the humerus. It appears to extend over the length of six vertebræ and to be rather longer than the humerus. The preservation is bad, owing to the dried condition of the animal at the time of fossilization. The length of the scapula exceeds 5 inches. At the humeral end it is 2 inches wide, and towards the anterior border the bone carries a moderate ridge of the usual type, such as might have supported a clavicle. Both anterior and posterior borders of the scapula are concave, and its least width did not exceed 1 inch. Its inner surface was concave, adapted to the convexity of the ribs.

There is no indication of precoracoid or coracoid bones A small

[1] Phil. Trans. Roy. Soc. vol. clxxxvi (1895) B, pl. i.

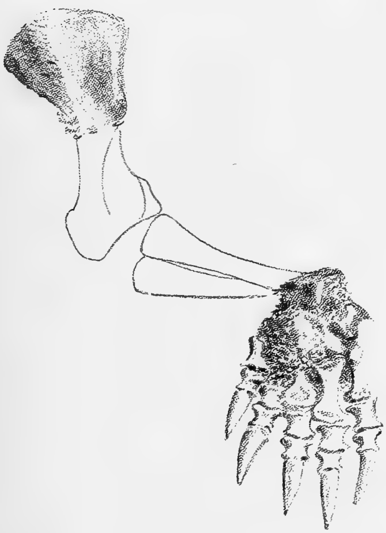
triangular impression, towards the median line of the vertebræ, is identified as displaced dermal plates.

The Fore-limb. (Figs. 2 & 3, pp. 329, 330.)

The new facts concerning the fore-limb are the characters of the humerus and the impression of the superior surface of the left fore-paw.

The humerus proves to be a little more than 4 inches long, 2 inches wide at the proximal end, and a little wider at the distal end. The inner side of the bone is concave; the outer side is straighter, and both articular ends are in the same plane. The proximal articulation is convex from side to side above and concave below, with the inner side of the bone considerably thickened and rounded at the terminal cartilaginous surface. The concavity on the underside extends halfway down the shaft, being bounded externally by the rounded ridge of the radial crest, which becomes most elevated towards the middle of the shaft, where it terminates in the manner usual in Theriodonts. The foramen at the distal end on the ulnar border is not preserved. The angle on the superior outer border of the lower third of the shaft is more pronounced than in any known Anomodont humerus; and the lateral surface which extends from this angle to the radial articulation is obliquely flattened for a length of 1 inch. The thickened flattened inner side of the bone at the proximal end is distinctive. There is no indication of the characters of the underside of the distal end of the bone. The shape of the bone conforms better to the Theriodont than to the Dicynodont type, in which the known examples are relatively wider at the distal articular end.

Fig. 2.—*Bones of the fore-limb of* Eurycarpus Oweni (*about* $\frac{1}{3}$ *nat. size*).



[The distal end of the humerus and the ulna and radius here shown in outline are drawn from the original slab in the Natural History Museum and from a plaster cast of the space between the two specimens.]

The outlines of the radius and ulna are but dimly indicated in the slab, as if a thin layer had scaled off and removed the impression of the undersides of those bones. The distal end of the

radius, which is not seen in the Bain slab, twists round the ulna, and is prominent, showing something of its truncated distal extremity, which might have been mistaken for a large carpal bone if the Murray slab only had been known. Its extremity is rather more than $\frac{1}{2}$ inch wide. The forearm is $3\frac{1}{2}$ inches long.

The hand is bent backward so as to display its upper surface, and is a beautifully sharp impression of the phalangeal bones. But a large ovate area over the carpus and metacarpus has the appearance of being covered with a patch of armoured skin, in which the granules seem to be thickly grouped as though they were in contact with each other. A similar granular condition of the bones of the forearm was suspected by Owen to be indicative of the dried skin. The granules are very distinct on the underside of the humerus, especially at the proximal end, and appear to indicate that the front of the animal was thus protected. This condition is probably most comparable with the condition of the limbs in snapping turtles and some tortoises, in which I have found bony granules beneath some of the horny tubercles.

Fig. 3.—*Hand of* Eurycarpus Oweni (*about $\frac{1}{2}$ nat. size*).

The specimen shows the outer distal carpal bone, which is inch long, longer than wide, concave at the sides, compressed superiorly and truncated distally, forming a slight talon on the inner side of the fifth metacarpal bone, with which it articulates. Another carpal is above the fourth metacarpal bone, but these are the only carpal bones which are not obliterated by the covering dermal armour.

Only the three outermost metacarpals are shown. They are well defined by their forms, which are elongated, and transversely expanded at the distal and proximal ends. The fifth bone is less expanded at the proximal end, where the articular surface is convex from front to back. The wide distal ends of the fourth and third metacarpal bones show in each a triangular impressed area just above the terminal articular surface. The distal extremity of the second metacarpal is only indicated, while the first appears to be a massive bone about $\frac{1}{2}$ inch long, and therefore shorter than the other metacarpals, which is shaped like a digital phalange, only larger, and is parallel to the other bones. It appears that the carpus occupies a depth of 1 inch and a breadth of $1\frac{1}{2}$ inches. The metacarpal bones diverge very slightly as they extend forward, so that the transverse measurement over their distal extremities is 2 inches, while the length of this segment of the limb is about $\frac{3}{4}$ inch in its longest part.

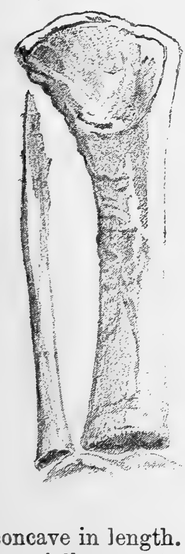
The bones of the phalanges of the digits are short, broad, strong, with the articular ends well defined. They are all in close contact, in a way that could not have been inferred from the previously-

known impression of the underside. As the digits are preserved, the interspace between the second and third digits is slightly greater than between the others. The number of bones in the fingers appears to follow the formula 2 . 3 . 3 . 3 . 3. It was already known that the terminal claw-phalanges were elongated and conical, but the middle one is 0·7 inch long, and longer than the two preceding phalangeal bones. They are all more or less rounded on the upper surface, but the first is obliquely flattened on the inner aspect, and the fourth and fifth are much more compressed from side to side than the second and third, and more arched from front to back. There is a mark in the slab prolonged beyond the fifth claw, and others for a length equal to the bone, which may indicate the original extent of the horny claw (Pl. XXI, *H*). The length of the claws and the mobility of the joints in the fore-limb, no less than the form of the bones, are suggestive of a burrowing habit in this animal.

The Hind-limb. (Fig. 4.)

The femur was very imperfectly preserved in the Bain slab, where it appears to be 4·4 inches long, and to have the proximal articular head directed inward in a way which may approximate to the form of the bone in known Theriodonts. This specimen shows that the distal end of the femur (Pl. XXI, *F*) was subquadrate, not more than 1 inch thick, flattened on the inner and hinder surfaces, with the distal surface rounded a little from front to back, but so truncating the bone as to show that the femur may have been carried in a more vertical position than is usual in living reptiles. Its form approximates to the bone which I have regarded as the femur of *Rhopalodon* more than to that of *Cynognathus*.

Fig. 4.—*Tibia and fibula of* Eurycarpus Oweni (*about* $\frac{2}{3}$ *nat. size*).



The tibia and fibula are well displayed in the Murray slab. There is the same slender mammalian proportion of fibula which has already been detected in *Microgomphodon*, and this appears to be a Theriodont character. This segment of the hind-limb is 3·7 inches long.

The tibia is slightly enlarged at the distal end, where it measures $\frac{7}{10}$ inch from side to side, and appears to terminate in a truncated articular surface, with the border slightly rounded. The proximal end is more expanded, and its width is 1·2 inches. The posterior margin of the shaft is more concave in length. The bone shows some evidence of compression, especially towards its extremities. The proximal extremity consists of two surfaces which are inclined to each other at a large angle. The smaller posterior surface is terminal and articular, and

margined by a slightly tumid round border, such as often margins cartilaginous surfaces. With this area the distal articular end of the femur is in loose contact. The other surface, which is longer than wide, looks as though it might have supported a patella. No trace of such a bone is preserved.

The slender fibula is slightly curved; it appears to extend from the posterior outer extremity of the tibia, and ends distally in a moderately expanded truncation.

Below these bones is a large tarsal bone apparently, as in *Pareiasaurus*. The fibula, which is prolonged a little farther distally than the tibia, appears to be attached to the inner margin of the same bone. The specimen, however, is not clear at this point, where a fracture has passed through the tarsal bone, removing the impression of the hind foot. The foot was probably lost when the slab was collected by the original finder, for Mr. Thomas Bain, who had seen it, only spoke of one hand as pointed out to him. I have some reason for believing that the other half of the specimen, showing the right side of the animal, may still exist in some private collection in Cape Colony, though I have been unable to hear of it.

The recovery of the missing half of the Murray slab, with evidence of the skull and pelvis which it would give, is greatly to be desired in order to complete our knowledge of this fossil animal.

Armour. (Pl. XXI, *v.a.*)

Besides the armour which appears to have been present upon the limbs, the fore part of the body carries upon the ribs and vertebræ large granules, and thin oblong bony plates, which may measure $\frac{1}{2}$ inch in length and $\frac{3}{4}$ inch transversely, but the markings are too obscure for description. They are evidence for armour on the flanks of *Eurycarpus*, with the plates shown in one close-set longitudinal row on the under part of the front of the body, such as occur in Labyrinthodonts.

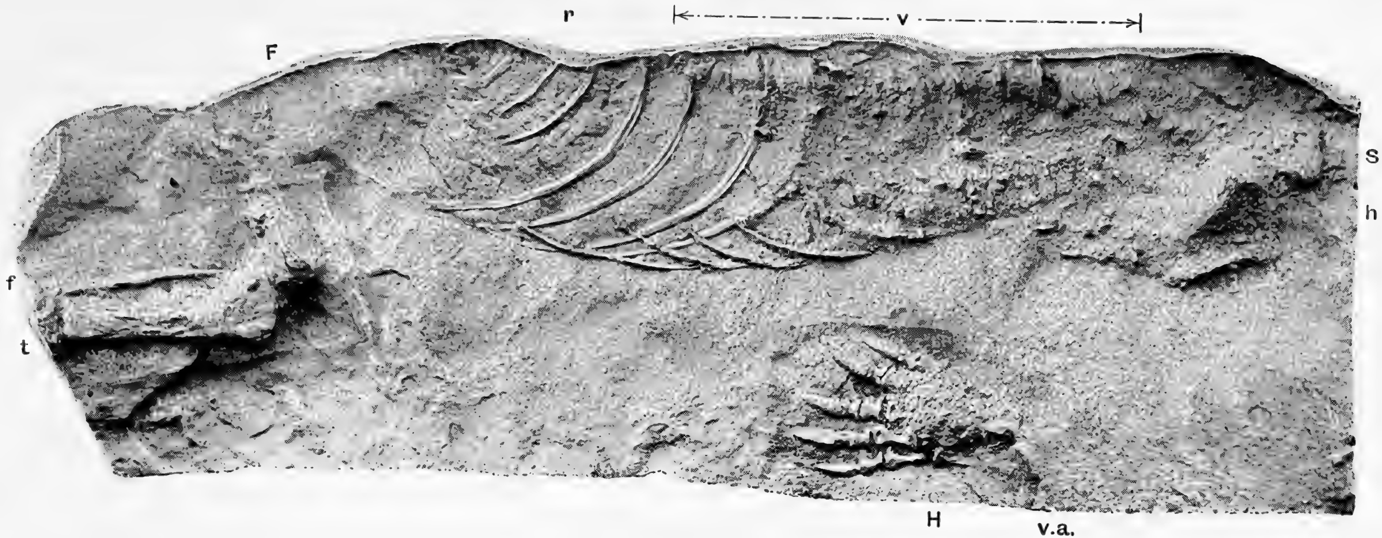
The locality, Sneeuwberg, from which this animal was obtained, had already yielded to Mr. A. G. Bain *Lycosaurus pardialis*, *Tigrisuchus simus*, *Cynosuchus suppostus*, *Scaloposaurus constrictus*, and *Dicynodon leoniceps*. It would therefore appear to be one of the chief localities for the Lycosaurian types of Theriodontia, and to be on the horizon of the *Dicynodon*-beds.

EXPLANATION OF PLATE XXI.

Photographic reproduction of the cast of a portion of the left side of the skeleton of *Eurycarpus Oweni*, about one-third of the natural size. It shows the ventral aspect of the vertebral column (*v*) and ribs (*r*), with traces of armour (*v.a.*), the shoulder-girdle (*S*), and portions of the fore-limb (*h, H*) and hind-limb (*F, f, t*).

Discussion.

Dr. H. Woodward spoke, and Mr. A. Smith Woodward replied on behalf of the Author.



CAST OF A PORTION OF THE SKELETON OF *EURYCARPUS OWENI* (about $\frac{1}{3}$ nat. size).

21. *On an* Intrusion *of* Diabase *into* Permo-Carboniferous Rocks *in* Frederick Henry Bay (Tasmania). By T. Stephens, Esq., M.A., F.G.S. (Read December 20th, 1899.)

[Plate XXII.]

The most striking features in the geological structure of by far the greater part of Tasmania are the lofty mountain-ranges, which, to the casual observer, appear to consist solely of diabasic greenstone, or dolerite, as it is variously termed. Tasmania is in extent nearly as large as Ireland, and this rock occupies the summits of all the mountains in the eastern half of the island, extending well into the western half in the central and southern districts, and reaching a maximum altitude of 5069 feet above sea-level. But the diabase is not confined to the mountain-ranges. It crowns almost every considerable hill within the area described; it is exposed at numerous points in the river-beds and valley-bottoms; it fringes the margin of basaltic lava-flows of Tertiary age; and its presence has been detected elsewhere by boring through overlying sedimentary strata.

The oldest sedimentary rocks exposed in the south-eastern quarter of Tasmania belong to that division of the Upper Palæozoic Series which in Eastern Australia and Tasmania is classed as Permo-Carboniferous. The question of the relations of these sediments to the diabase has often been raised. Were they quietly deposited during a long unbroken period against and around vast masses of igneous rock previously cooled and denuded? Or is the diabase an intrusive rock, the existence of which in the shape of vast dykes and sills has been disclosed through the removal of overlying strata by the ordinary processes of denudation? The former theory seems to have been widely accepted as the basis of the geological history of the eastern half of Tasmania, though not without occasional adverse criticism from competent observers who had noted evidence to the contrary at isolated points. My own opportunities of observation over the whole area in question have long since led me to conclude, firstly, that the central plateau is not a vast boss of ancient volcanic rocks, but rather a ring or network of massive dykes and sheets of diabasic greenstone, which traverse all the sedimentary rocks of pre-Tertiary age; and, secondly, that there is no known instance in which the diabase of Eastern Tasmania can be proved to be anterior to the deposition of the Permo-Carboniferous Series.

The question is one of considerable importance, even from an economic point of view, for the principal coal-seams crop out on the flanks of lofty ranges in which the diabase is a predominant feature. The problem is one of those which can never be fully solved without a systematic geological survey of the whole country, and this, unfortunately, has not yet been under-

taken in Tasmania. All that can be done at present is to collect materials for safe generalization by noting and sifting the evidence obtainable from natural sections, or otherwise; and the primary object of this paper is to correct a misapprehension which appears to have been founded upon a paper brought before the Geological Society rather more than half a century ago.

In the Quarterly Journal for 1847 appears a communication by the late J. B. Jukes[1] which gives an admirable general description of the chief geological features of the south-eastern portion of Tasmania. Speaking of these in general terms, and remarking that he had no time for a detailed examination of the country, the author says (*op. cit.* p. 245):—'The two principal rock-masses of the south-eastern portion of Tasmania are a very massive, rudely columnar greenstone, and the sandstone of the Palæozoic formation.... The sedimentary and the igneous rocks are so interlaced and entangled one with the other, and their apparent relations at the surface so different in different localities, that nothing but a careful and minute survey, laid down on maps of a large scale, will ever be able thoroughly to elucidate them.' Of the relations of the sedimentary rocks to the greenstone of Mount Wellington, Jukes speaks in carefully guarded terms; but he mentions two sections on the other side of the Derwent estuary, as affording evidence of the non-intrusive character of the igneous rock. With reference to one of these, which is described as being 'about a mile from a place called Ralph's Bay Neck, on the S.E. side of North Bay,' he says (*op. cit.* pp. 246–47):—'In this case a dark, rudely columnar trap-rock ended in a succession of small cliffs and terraces in one direction, upon which terraces and against which little cliffs rested the sandstone perfectly undisturbed, and evidently in the position in which it had been originally deposited. A parallel instance was observed in the cliffs a little to the eastward of the entrance of Port Arthur. It appears, then, that there are masses of greenstone both of more ancient and more modern date than the Palæozoic rocks.'

When my attention was first called to this passage, I had some difficulty in determining the position of the section described, for no such name as North Bay appears on any map of the present day. Ralph's Bay Neck was easily identified; but I had already examined all the coast-sections in the neighbourhood, except a small projecting point on the shore-line of Frederick Henry Bay, which was at the time inaccessible, owing to a high tide. A second visit to this point cleared up all doubt as to its identity with the first of the two places mentioned. Here, on the face of a cliff rising to a height of about 80 feet above high-water mark, are the 'small cliffs and terraces of trap-rock,' which, to an observer at a distance, would appear to be supporting a mass of sandstone, or other similar rock, 'undisturbed and . . . in the position in which had been originally deposited.'

[1] 'Notes on the Palæozoic Formations of New South Wales & Van Diemen's Land,' vol. iii, pp. 241–49.

An examination of the section, however, reveals very different conditions. The sedimentary rocks to the left have been so indurated and altered, that the planes of stratification are in many places traceable only on the weathered face. From the same cause the rock, at first sight, appears to be barren of fossils; but I found sufficient traces of *Fenestella*, *Spirifer*, *Productus*, etc. to identify it with the limestones interstratified with shaly bands, which constitute the lower members of the Permo-Carboniferous Series in South-eastern Tasmania. The shale has been converted into chert, and the limestone in some places into an intensely hard whitish marble. The direction of their dip is about west-south-west, and the face of the section is nearly in line with their strike. They occupy the whole of the rocky point to the east and south of the section, the mudstones and sandstones of the upper portion of the marine series showing themselves to the south and west at no great distance, with some indications of an intervening fault throwing up the lower portion of the series.

The dark rock to the right, in the lower part of the section (see Pl. XXII), is the ordinary diabase of Eastern Tasmania, showing the finely crystalline, granular structure, which is noticeable in this rock wherever it is found in contact with the original cooling-surface. Its main constituents are plagioclase-felspar and augite, and a microscopic examination would probably disclose the ophitic structure, which has been shown by a competent local authority, Mr. W. H. Twelvetrees, to be an invariable characteristic of the Tasmanian diabase. The rock is rudely columnar where exposed on the coast, and it extends for a few hundred yards to the north and west, being succeeded by Permo-Carboniferous mudstones apparently undisturbed, but extensively denuded. The junction is hidden from view by the mud-flats and sand-dunes of Ralph's Bay Neck.

The diabase, with a more coarsely crystalline structure, appears again at many points within a radius of a few miles in the massive form described in the first part of this paper. Of its intrusive character at the point described there can now be no doubt, and the evidence afforded by the section seems to show that this is not a case of an ordinary lateral thrust. It suggests rather that the whole mass of the altered rocks has been bodily lifted from its original position by the intrusive sheet, and that, to match the peculiar fracture of the bedding-planes exhibited by the section, there must be, far down below the present sea-level, a corresponding series of steps, or 'benches,' in the undisturbed formation, from which the portion now visible on the surface has been torn away.

The other section mentioned by Jukes is on the face of a lofty precipitous cliff to the east of the entrance of Port Arthur. The place is reported to be inaccessible for any purpose of close examination; but on the other side of the estuary I have noted many interesting sections in which the diabase occurs as an unmistakable sill,' with altered sandstone immediately overlying it.

How are these two conflicting accounts to be reconciled? It is unnecessary to point out that a report by so competent an observer as Jukes, on a formation which he had personally examined, could not be lightly set aside, and the explanation is not far to seek. Between 1842 and 1845, H.M.S. *Fly* was engaged in surveying the eastern coast of Australia and Tasmania, and Jukes held the position of naturalist to the expedition. During the progress of the survey, he appears to have made a trip from Hobart to Port Arthur, at the southern extremity of Tasman's Peninsula, where his ship was temporarily stationed. The only direct means of conveyance at that time was the boat which carried mails, etc. to the peninsula, and no deviation from its regular course would be practicable. The first part of the route was by way of Ralph's Bay to Frederick Henry Bay. The Neck would be crossed by means of a tramway, which has long been disused, and the traveller would pass the section which is the subject of this paper at a distance of about $\frac{1}{4}$ mile, but he would have no opportunity of landing. Jukes mentions several places which he personally visited, including quarries from which fossils were obtained; the nearest of these, however, is distant about 18 miles from the Frederick-Henry Bay section, and most of them are on the other side of the Derwent estuary. The paper appears to have been written three or four years after the visit to Tasmania, and this might account for a slight want of continuity and clearness in the reference to distinct localities. The sketch, fig. 1, *op. cit.* p. 247 (there is no fig. 2), which immediately follows the account of the Frederick-Henry Bay section, represents the cliff-section mentioned in the next two lines, which is cited as a parallel instance. The latter is more fully described in the second part of Jukes's paper, and was probably seen by him from the deck of the *Fly*.

PLATE XXII.

Section showing the junction of diabase and altered sedimentary rocks in Frederick Henry Bay (Tasmania). Reproduced from a photograph.

Junction of Diabase and altered sedimentary Rocks in Frederick Henry Bay (Tasmania).

22. NOTES *on the* GEOLOGY *of* GILGIT. By Lieut.-Gen. C. A. McMAHON, F.R.S., F.G.S. (Read March 7th, 1900.)

[PLATE XXIII.]

CONTENTS.

PART I.—INTRODUCTION.

MY son, Capt. A. H. McMahon, C.S.I., C.I.E., F.G.S., Political Agent, Malakand, when stationed at Gilgit, made field-observations and collected rock-specimens for me in the course of numerous traverses through the Gilgit area.

I have not had an opportunity of visiting the region covered by this paper; but I have seen much of the neighbouring Himalaya, and I have had the advantage of correspondence not only with my son, but also with Capt. J. R. Roberts, I.M.S., regarding the geology of Gilgit. I am greatly indebted to Capt. Roberts for much valuable information, for field-observations undertaken on my behalf, for careful drawings of sections, and for numerous additional specimens supplementing those sent by my son. I cannot overrate the obligations under which I am to him.

A sketch-map (see p. 344) has been prepared to accompany this paper, compiled mainly from the map of the Pamirs (1896) by H. Sharbau and the Right Hon. G. N.—now Lord—Curzon; and from the map of Astor and Gilgit (1883) by the Surveyor-General of India.

The geology of the neighbouring parts of Kashmir has been described by Mr. R. Lydekker, F.R.S., in vol. xxii (1883) of the Memoirs of the Geological Survey of India, and in papers published in the Records of the same Survey. The map published with the above-mentioned Memoir shows the geology of Kashmir as far as Astor, at which place this paper takes up the geology.

An account of the geology of Yárkand, Káshgar, Wákhan, the

Great and Little Pámirs, and other territory in Central Asia adjoining the Gilgit area, by W. T. Blanford, LL.D., F.R.S. based on the collections and notes of the late Ferdinand Stoliczka, Ph.D., will be found in the Scientific Results of the 2nd Yárkand Mission, Calcutta, 1878. A description of thirteen rock-specimens from the Little Pamir by T. H. Holland, A.R.C.S., F.G.S., Geol. Surv. India, is given in the Natural History Results of the Pamir Boundary Commission, Calcutta, 1898.

As I purpose so far as possible, for the sake of brevity, to give results rather than dry technical details, I may mention that my petrological remarks are based on a careful study of 156 thin slices of rocks, and a still larger number of special chemical and microscopical studies of fragments of these rocks.

Gilgit has not yet been visited by a professional geologist, but we are indebted to two gentlemen for some knowledge of the geology of the district.

The first observer to write about the rocks of this region was Surgeon-Capt. G. M. Giles, I.M.S.,[1] who traversed the Gilgit Valley as far as the Kilik Pass. He considered that the rocks presented a monotonous uniformity, and that, as all of them were thoroughly metamorphic, it would be useless to attempt to assign to them a relative position in time. He noted[2] the occurrence of crystalline limestone at Hini, and again between Pasu and Khaibar; and of a pale compact limestone between Khaibar and Gircha. He noted at various points the outcrop of masses of gneiss, garnetiferous mica-schists, granite, micaceous schists, slaty schists, greenstones, and slates intercalated between the outcrops of limestone, and mentions that between Pasu and Khaibar the slates are sufficiently fissile to yield good roofing-material. The author's observations, however, are not continuous; he does not appear to have left the beaten track; and when the road passed over alluvium, snow, or talus, which it did for many miles at a stretch, his record regarding the solid rocks remained a blank.

Capt. Giles does not appear to have suspected that any of his gneiss was an intrusive rock, or that much of the metamorphism which he considered so monotonous had its origin in the contact-action of these igneous masses. He kept a record of the dip and strike of the rocks seen by him, and noted it on a sketch-map. From Gilgit to the Kilik Pass the strike is correctly represented as being east and west, with the exception of that between Nomal and Safed Ab; and between Ghulkin and Gircha the strike is said to be more or less north-west and south-east.

Capt. Giles's observations are valuable as far as they go; but they do not contain anything to throw light on the age of the rocks, or their mutual relations.

[1] The paper has not been given to the public.

[2] The determination of the rock-names was made by Mr. H. B. Medlicott, F.R.S., then Director-General of the Geological Survey of India.

The next observer who visited this region was Mr.—now Sir—W. Martin Conway, who made a large collection of rock-specimens, which were examined by Prof. T. G. Bonney, D.Sc., F.R.S., and Miss C. A. Raisin, D.Sc. The report on these specimens by the above-named authors forms part of the appendix to Sir Martin Conway's work on 'Climbing & Exploration in the Karakoram Himalayas,' 1894. An account of the results obtained was also given in a paper read before the Royal Society.[1]

Sir Martin Conway's main object was the exploration of high peaks and glaciers, from a mountaineering rather than a geological point of view; and for that reason, probably, his collection, though extremely rich from peak and glacier, is extremely poor from the valleys. I can only find the description of one specimen in a stretch of 50 miles from Bunji to Chalt.

This hiatus of specimens from the main line of communication up the Gilgit-Hunza Valley, however, is to some extent compensated for by the abundance of the specimens collected in the Bagrot, Hispar, and Biafo Valleys; and as the rocks in those localities are on the same strike as some of the rocks dealt with in the present paper, Sir Martin Conway's specimens form a valuable supplementary collection to the specimens sent home by my son and Capt. Roberts.

Sir Martin Conway did not proceed higher up the Gilgit Valley than Hunza, where he turned eastward towards the Hispar and Biafo Glaciers. The traverses to the Kilik and Darkot Passes, to Chilas, up the Ashkurman Valley, and to Nanga Parbat, described in this paper, covered new ground. Moreover, as Sir Martin Conway does not appear to have recorded any field-notes (beyond the dip and strike) regarding the relations of the rocks to each other, there seems room for supplementary observations as a step towards the elucidation of the geology of the Hindu Kush.

To Prof. Bonney and Miss Raisin all geologists who may hereafter work in the Gilgit region will be under great obligation. Their careful study of the numerous specimens submitted to them contains a mine of valuable petrological information. I personally feel greatly indebted to them for their valuable work; and I have found it of great help, especially in the matter of the crystalline limestones, as it enabled me to trace the connexion between the Carbo-Triassic limestones of Kashmir, mapped by Lydekker, and the great limestone-series of the Gilgit Valley.

With these preliminary remarks, I will now proceed to describe the geology of the Gilgit area, as far as the information at my disposal enables me to do so. I trust that, at all events, my remarks may suggest points for enquiry and observation to future explorers in this difficult mountainous country, where the precipices are stupendous; where joints and cleavage-planes closely simulate bedding; and where field-investigations are often brought

[1] Proc. Roy. Soc. vol. lv (1894) p. 468.

to a dead stop by the ground becoming, even to an expert climber, quite inaccessible.

I propose to give, in the first instance, a summary account of the granites intrusive in the Gilgit area; then to pass on to a brief survey of the Gilgit rocks, considered topographically, and to conclude with some general remarks.

(1) The Baltit Hornblende-Granite.

This is the most basic of all the Gilgit granites. Felspar appears to predominate over quartz. Biotite in large leaves, sometimes twinned, is usually abundant, and is strongly pleochroic in reddish-brown and brownish-yellow tints. It polarizes vividly in blue, red, and green.

Hornblende is fairly abundant. It is pleochroic in tints of green. It is usually much corroded and eaten into by the ground-mass; basal sections are sometimes idiomorphic, otherwise the mineral occurs usually in allotriomorphic aggregates, often associated or intergrown with biotite. In one slice all the hornblende is idiomorphic. In hand-specimens it is black, and appears to be a basic species rich in iron. It fuses readily in the flame of a Bunsen burner to a black glass without the aid of a blowpipe, and the specific gravity of an isolated fragment was found to be 3·368.

The proportion of plagioclase to orthoclase varies in different slices. It usually belongs to the oligoclase species, though andesine is also present. Zonal structure and pericline-twinning are common. Granophyric structure is sometimes prominent, and microcline is occasionally present.

Apatite is generally to be seen, and is sometimes abundant. Sphene, a colourless epidote, magnetite, and a few crystals of schorl also occur, and the two former are sometimes plentiful. The epidote in one of the slices closely resembles white augite, and it is sometimes difficult to say which is present, especially as the mineral is associated with hornblende.

Three of the slides contain allanite. One of them shows a lath-shaped crystal of this mineral which extinguishes at 40°, surrounded on three sides by epidote. Another slide, which does not contain any epidote, exhibits two idiomorphic prisms of allanite, one of which is twinned. The mineral is brown in reflected light: by transmitted light it shows strong pleochroism, changing from a reddish or chocolate-brown to brownish-yellow. The refraction of the mineral is strong, and it polarizes in the dull red and yellow of the first of Newton's orders. The twins extinguish simultaneously at about 43° to the twinning-plane.

The macled crystal of allanite much resembles the twinned allanite figured and described by Hobbs.[1] In that mineral both twins extinguished simultaneously at 36° from the twinning-plane. The maximum angle of extinction in the case of a dark mineral

[1] Amer. Journ. Sci. ser. 3, vol. xxxviii (1889) p. 226.

like that now described, however, is difficult of exact determination, as the mineral remains more or less dark during a revolution of 20°, and it is hard to say when the maximum is reached. Moreover, the maximum extinction with the vertical axis seems to vary in different species. It is usually said to be from 34° to 37°; but a specimen, quoted by Dana from Hitterö,[1] showed it at 40° or 41°.

The structure of the Baltit Hornblende-Granite is typically holocrystalline. It bears marks of strain, but tessellated quartz is extremely rare.

(2) The Hatu Pir Granite.

Hatu Pir,[2] a mountain rising 10,254 feet above sea-level, situated near the confluence of the Astor and the Indus, is composed of this granite. It is a rock which always contains dark mica as an original constituent. The mica is strongly dichroic, and usually polarizes brilliantly; occasionally it is altered to chlorite.

The quartz in one slide equals the felspar in amount, but in the others it is less abundant than the felspar. As a rule, orthoclase predominates over plagioclase: the latter is mainly oligoclase, with an occasional mixture of andesine. The oligoclase was one of the first minerals to crystallize out of the magma, and crystals of it are enclosed in the orthoclase. Zonal structure and twinning on the Carlsbad, pericline, and albite laws are common. The felspar is sometimes fairly idiomorphic.

Muscovite, or silvery mica, occurs in a few slides, but it may be a secondary product. A little magnetite is almost always present; epidote, sphene, and allanite also occur.

More or less apatite is found in every slide save one. It is granular in form, and rarely exhibits crystallographic outlines. This habit is very characteristic of the apatites in the Gilgit granites.[3] The hand-specimens react strongly for phosphoric acid; but in order to remove all doubt about this mineral, I subjected a thin slice, after examination under the microscope, to the action of nitric acid. This completely dissolved the colourless granular mineral, and the solution thus obtained reacted unmistakably for phosphoric acid, showing that it was apatite and not zoisite. Optical tests were also applied.

Zircons are present, but are only occasionally seen in thin slices. Schorl is still more rare.

Some of the hand-specimens of this granite show decided parallelism of structure, but this is not observable under the microscope. Marks of strain, however, are usually present in some form or other; strain-shadows are common; felspars are cracked; and portions of the quartz break up under crossed nicols into a

[1] 'System of Mineralogy' 6th ed. (1892) p. 523.

[2] Named after a Mahomedan saint.

[3] Zirkel remarks on 'the apatites in massive granites being generally far more broad and short' than the long thin prisms in certain other granites described by him, 'U.S. Geol. Explor. of 40th Parallel' vol. vi (1876) p. 49.

mosaic, in which some of the felspar is occasionally involved. This mosaic at times behaves after the manner of an intruder cutting across quartz and felspar, like granite permeating and penetrating sedimentary rocks. Connected with this phenomenon is the frequent occurrence of granophyre, and the intense erosion and perforation of biotite, felspar, and other minerals by the quartz of the granite. (See Pl. XXIII, fig. 4.)

Another structure met with in the Hatu Pir Granite may be noticed in passing. Sometimes the quartz, instead of breaking up into granulitic, tessellated, or more or less rounded granules, assumes very irregular and varied outlines: the individual granules throwing out finger-like processes, and dovetailing one into the other in a very complex way. Fig. 1 (Pl. XXIII), photographed from one of the slides, illustrates this structure. In the following pages I shall speak of it as the amœboid structure. Like the tessellated structure (of which it is only a variety), it indicates that final crystallization set in under conditions of great strain.

The Hatu Pir Granite reminds me strongly of the gneissose granite of Dalhousie, and, like the latter, it is rich in microcline.

(3) The Acid Variety of the Hatu Pir Granite.

The Hatu Pir Granite is cut through by another biotite-granite, so closely resembling it that I regard it as an acid variety of the same rock belonging to a later phase of the eruption.

Mineralogically considered, the acid variety is composed of the same minerals as the normal Hatu Pir Granite, namely, quartz, orthoclase, oligoclase, a little andesine, biotite, a little muscovite or silvery mica,[1] magnetite, epidote, sphene, zircon, allanite, and a very little schorl.

The granite appears to have emanated from the Hatu Pir magma after the relative proportions of the constituents had been somewhat altered by the crystallizing-out of some of the basic material. In the Hatu Pir Granite free quartz falls below felspar in amount in nine cases out of ten, and equals it in the remaining case. In the variety under description the quartz falls below felspar in four cases only, equals it in one, and exceeds it in four cases out of a total of nine. These figures seem to show an increase in the proportion of silica.

A diminution in the proportion of alkali present seems also to have taken place. In the Hatu Pir Granite orthoclase predominates over plagioclase in eight out of ten cases; whereas in the acid variety it does so in five only out of nine cases.[2]

A diminution is observable in some of the more basic minerals. Biotite, magnetite, and apatite are, generally speaking, less abundant than in the parent-rock, and sphene only occurs in one slice.

[1] The muscovite I regard as an original, and the silvery mica as a secondary mineral.

[2] The percentage of alkali is considerably higher in orthoclase than in plagioclase.

I have noted the solvent action of the quartz on the micas and felspars of the Hatu Pir Granite. This action, as might have been expected, is even more noticeable in the variety under consideration. For instance, in one of the specimens the felspar is deeply corroded by the quartz. The latter mineral nibbled into the felspars and formed bays all round their margins. It also penetrated into the heart of crystals, forming gulfs and lakes, so to speak, and cut up what were once large felspars into strips of fantastic shape. In other examples the quartz has penetrated felspars in a way that recalls the structure of perthite. That these strips are quartz and not waterclear felspar, however, I have proved in many cases by obtaining a well-defined cross in converging polarized light.

The acid variety has suffered even more than the Hatu Pir Granite itself from dynamical action. Most of it is strongly foliated, and two of the specimens from Nanga Parbat are very schistose.

(4) The Askurdas Muscovite-Granite.

This granite is composed of quartz, orthoclase, oligoclase, and muscovite.

Felspar predominates over quartz, and orthoclase over plagioclase in three out of four cases. A little andesine is present in two slides. The Askurdas rock differs from the Hatu Pir normal and acid granites in the total absence of apatite, allanite, epidote, and sphene, and the sparseness of magnetite and biotite. Some microclines and granophyres are to be seen in one slide.

The structure of the rock is granitic, but it bears evidence of strain, and some of the quartz and felspar is broken up into tessellated grains. In this rock also quartz appears as a corrosive agent, eating into the felspar in veins and blebs, and cutting up the orthoclase into strips and fragments, which it involves in its flow.

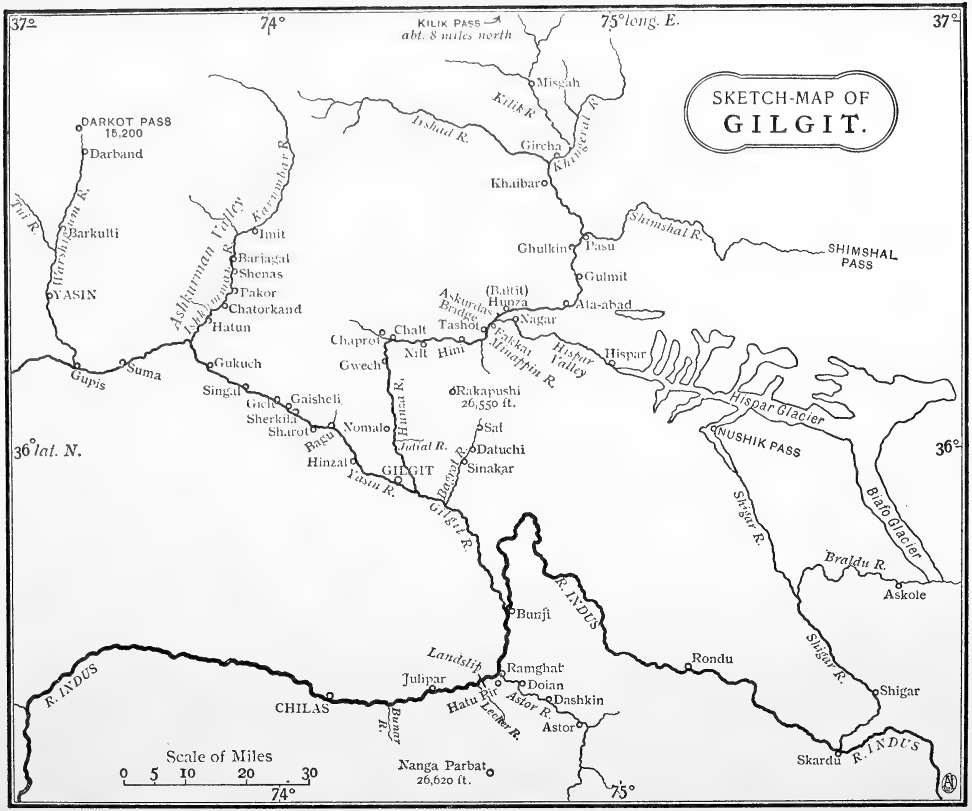
Two of the four slices contain pale pink garnets, and one a little calcite. Some secondary silvery mica is occasionally present, as well as original muscovite.

The quartz contains strings of liquid cavities with moving bubbles.

The garnets are very prominent in three of the hand-specimens.

(5) The Aplites.

These occur as small veins in the crystalline limestones. The felspars in the aplite are orthoclase, microcline, and plagioclase: the last-named does not exhibit any twinning. A little magnetite is present, and the samples are much stained with ferric oxide. Much of the quartz is broken up into a mosaic, and in one slide there is strong parallelism of structure. The larger quartzes either form eyes, or have been drawn out into long sausage-shaped crystals.


SKETCH-MAP OF
GILGIT.
KILIK PASS
abt. 8 miles north
37°
74°
75° long. E.
36° lat. N.
36°
DARKOT PASS
15,200
Darband
Barkulti
YASIN
Warshigum R.
Tui R.
Gupis
Suma
Ashkurman Valley
Ishkuman R.
Karumbar R.
Imit
Barjagal
Shenas
Pakor
Chatorkand
Hatun
Gukuch
Singal
Gich
Gaisheli
Sherkila
Sharot
Bagu
Nomal
Hinzal
Yasin R.
GILGIT
Gilgit R.
Hunza R.
Julial R.
Bagrot R.
Sat
Datuchi
Sinakar
Rakapushi
26,550 ft.
Chaprot
Chalt
Nilt
Hini
Gwech
Tashot
Askurdas Bridge
(Baltit)
Hunza
Nagar
Fakkar
Minappin R.
Hispar Valley
Hispar
Hispar Glacier
NUSHIK PASS
Biafo Glacier
Braldu R.
Askole
Shigar R.
Shigar
Skardu
R. INDUS
Rondu
Ata-abad
Gulmit
Pasu
Ghulkin
Shimshal R.
SHIMSHAL PASS
Khaibar
Gircha
Khunjerab R.
Misgah
Kilik R.
Ishkuman R.
Bunji
Landslip
Ramghat
Doian
Dashkin
Astor R.
Astor
Hatu Pir
Lechar R.
Julipar
CHILAS
Bunar R.
Nanga Parbat
26,620 ft.
Scale of Miles
0 5 10 20 30

Part II.—Topographical Description of the Rocks.

I now pass on to describe the geology of the Gilgit area, as far as the information at my disposal enables me to do so. I think that it will conduce to clearness if I begin at the extreme southern point in the Gilgit section, and thence work my way northward to the high passes leading up into the Pamirs. (Map, p. 344.)

(1) Nanga Parbat.

This fine mountain rises to a height of 26,620 feet, and even at a distance of 95 miles, my nearest approach to it, forms a magnificent object.[1] My son is the first to give us any geological information regarding this giant of the Hindu Kush. He ascended the Rupal Nalah (ravine), which leads out of the Astor Valley and runs along the southern face of Nanga Parbat. It was a little farther up this nalah that the Alpine travellers, Mummery and Hastings, lost their lives in 1896. My son went up the Tashing Glacier and the Biji Glacier He writes:—

'These two glaciers are fed directly and entirely from the highest peaks of Nanga Parbat, the Biji Glacier being fed by the highest peak itself. Both slope back to the foot of a bare sheer cliff falling straight down from the very tops of the peaks. The débris on each glacier is in each case all composed of one type of rock, as shown by the specimens; and as this débris comprises the detritus from the very summits of the peaks, one can gather with almost absolute certainty of what the peaks themselves are composed. There is no reason why the specimens have not themselves come from the central peaks; and if so, they are specimens of rocks from a higher elevation than any ever yet attained. I got them from a good way up each glacier.'

I have classed all four specimens as the acid variety of the Hatu Pir Granite (see p. 342). These specimens are highly schistose, and the Nanga Parbat rock may be called a granulite. It affords, I think, good examples of a foliated structure superposed on granite by pressure, fluxion, and shearing before final consolidation, and complicated, in the case of these particular rocks, by some local shearing after consolidation.

The difference in the colour of the bands seen in these specimens is not great, and appears to be due to two causes: firstly, the segregation of the biotite; and secondly, the drawing-out of porphyritic felspar-crystals into bands. In one specimen the porphyritic felspars, blunted and elongated, can still be made out on an examination of the hand-specimen with a pocket-lens. In another the process has gone further, and the rock has become schistose. A third specimen has evidently suffered severely from pressure and shearing. Not only have the felspar and quartz suffered in this way, but leaves of red brown mica have been drawn out into strings of imperfectly crystallized mineral matter resembling what I termed

[1] I was on a mountain over 9000 feet high.

cryptocrystalline mica in describing the gneissose granite of the North-western Himalaya. These strings and patches are not pleochroic, and give a very confused image in converging polarized light. They are partly fibrous, and are fringed with fine needles of what appears to be sillimanite, which radiate in all directions from the sides and ends of the cryptocrystalline mica. The needles exhibit straight extinction, a positive axis of depolarization, and many of them have the cross-partings characteristic of sillimanite. The occasional presence of this mineral in granite is well known.[1]

The last-described specimen also contains microscopic crystals of rutile, and some colourless mica which appears to be highly altered and degraded biotite.

(2) Astor to Ramghat.

The rock prevalent between Astor and Hatu Pir is a continuation of the acid variety of the Hatu Pir Granite, seen in force at Nanga Parbat, but not sheared to the same extent as the latter. It is foliated, however, and shows augen-structure. It resembles very closely some specimens of the gneissose granite of the North-western Himalaya.

My next specimen comes from the flank of Hatu Pir, and is the normal and older variety of the Hatu Pir Granite already described (p. 341). This specimen does not exhibit any parallelism of structure. I have no field-observations regarding the relationship of the acid to the normal variety of the granite at this point: that will be shown later on.

(3) Ramghat to Chilas.

This traverse enables us to obtain another view of the rock-succession seen between Astor and Ramghat. Leaving behind the quartz-diorite of the Ramghat cliffs, described on a subsequent page, the mountains along the left bank of the Indus as far as Julipar, a distance of 20 miles, are composed of the Hatu Pir Granite. The hand-specimens show more or less parallelism of structure, but this is not observable under the microscope. The quartz, however, is much broken up into tessellated grains, and some of the felspars are fractured.

The granite along this section is penetrated by dykes of greenish-grey pyroxenite which has a specific gravity of 3·107. It is a fine-grained holocrystalline mixture of dark hornblende and white pyroxene, the latter being rather subordinate to the amphibole.

The hornblende in this rock, which I shall speak of as the Lecher Pyroxenite, is of a pale brownish-green in transmitted light. It occurs in allotriomorphic grains and prisms, and in very thin slices shows a single diallage-like cleavage. Extinction from 12° to 17°. The pleochroism is hardly apparent in thin, but is very definite in thick slices.

The pyroxene is in some respects a puzzling mineral. It is colourless,

[1] E. S. Dana, 'Text-Book of Mineralogy' 2nd ed. (1898) p. 434.

and devoid of pleochroism in transmitted light. A single cleavage running parallel with the length of the grains or prisms is common, and this is interrupted, or crossed, by a set of cracks approximately at right angles to the first set. In some respects the mineral is suggestive of colourless epidote, and in others of white pyroxene. It is often difficult to distinguish the one mineral from the other, and in this case the difficulty is unusually great. I have decided in favour of pyroxene, for two reasons: firstly, because sections showing cross-cleavage exhibit an oblique emergence of an optic axis which is not seen in sections of epidote or zoisite showing cross-cleavage; and secondly, because the refraction of the mineral, though high, is lower than that required for epidote. I tested a considerable number of fragments, and in every case the refraction came out less than 1·740. The refraction would do for zoisite, but the double refraction of the mineral under consideration is far too high for that mineral. On the whole, I conclude that the mineral is pyroxene, and that the difficulty in its diagnosis arises from the fact that the first stages of alteration to a member of the epidote-zoisite family had set in.[1]

The pyroxenite just described is cut through by dykes and veins of the Askurdas Muscovite-Granite (see p. 343).

On the way from Ramghat to the Lecher River, a little before the pyroxenite is reached, and at the place marked on the sketch-map (p. 344), the hill-sides are covered with the débris of a great landslip which in 1841 completely blocked the Indus and caused a disastrous flood in the plains of the Panjâb. The débris consist of a diorite which is a holocrystalline mixture of hornblende and plagioclase, with magnetite and garnet as accessory minerals. The hornblende is of a dull brownish-green in transmitted light; it is feebly pleochroic in pale bluish-green and yellowish-green tints. A little of the plagioclase is visibly twinned, but it has the granular habit of quartz. It is full of microliths and globular inclusions which are probably micro-garnets. There are also gaseous and liquid inclusions with moving bubbles.

With this diorite is associated the acid variety of the Hatu Pir Granite. Viewed macroscopically it is a platy, sheared-looking rock. Under the microscope it gives good examples of amœboid structure.

Both the diorite and the acid granite had fallen down in large masses from high cliffs above the horizon of the Hatu Pir Granite, which is in force, as already mentioned, on both sides of the river between Rampore and Julipar. The cliffs being inaccessible, my son could not see whether the acid variety of the Hatu Pir Granite was intrusive in the diorite or whether the diorite had intruded into the granite.

Between Bonar and Chilas a hornblende-gabbro is common.

[1] The setting-up of such a change in an aluminous pyroxene such as leucaugite seems quite possible. Epidote on fusion yields lime-augite and anorthite [F. W. Clarke, 'Constitution of the Silicates' Bull. U.S. Geol. Surv. No. 125 (1895) p. 30]; and the conversion of augite through chlorite into epidote has already been recognized (C. R. Van Hise, 'Principles of N. American Pre-Cambr. Geol.' 16th Ann. Rep. U.S. Geol. Surv. (1894–95) pt. i, p. 690].

This rock consists mainly of massive black hornblende, with a little labradorite. The latter is penetrated by fine canals, and is remarkable for a peculiar arrangement of albite-twins which does not follow the pericline law.

(4) Ramghat to Gilgit.

I have already mentioned that the Hatu Pir Granite (normal variety) extends for some miles up to Ramghat on both the Astor and the Chilas roads. At Ramghat itself a rock comes in that might be called a quartz-diorite, but it is, I think, a slightly altered variety of the Baltit Hornblende-Granite. My specimen contains plagioclase (mainly oligoclase, but in part andesine), quartz, hornblende, magnetite, apatite, epidote, and allanite enclosed in epidote, and chlorite after biotite. The occurrence of allanite is characteristic of the Baltit Hornblende-Granite. In this specimen a general parallelism is observable in the arrangement of the minerals, and the felspars have been subjected to great crushing.

Capt. Roberts remarks, on the section between Bunji and Gilgit, that its 'characteristics are the innumerable granite-dykes and sheets that have intruded into the rocks, practically obliterating all trace of bedding, and giving rise to that form of landscape peculiar to granite—namely, rounded hill-tops with massive crags and well-marked joints.'

I am myself disposed to regard the rocks between Ramghat and Gilgit as an igneous complex composed of several varieties of granites. If it contains any rocks, or fragments of rock, which had originally a sedimentary origin, they were probably carried into position by the granites as included blocks, and have been altered out of recognition. Of the specimens sent me all are, petrologically considered, granites; and among them I recognize the Hatu Pir Granite, the Askurdas Muscovite-Granite, and the Baltit Hornblende-Granite, the last-named, as usual, containing allanite. One labelled 'schist' is petrologically a fine-grained granite, in which biotite is abnormally abundant. It contains orthoclase, plagioclase, quartz, hornblende, sphene, apatite, epidote, and zoisite. It might be a segregation in granite, but is more probably a portion of the Baltit Hornblende-Granite (the oldest granite of the area) caught up and metamorphosed by a later granite.

(5) Gilgit to the Kilik Pass.

The country around Gilgit is composed of a hornblende-plagioclase rock or diorite. This rock consists of a holocrystalline, granular mixture of hornblende, epidote, and plagioclase-felspar, in which hornblende slightly predominates. The last-named mineral is pleochroic in shades of (𝔞) brownish-yellow, (𝔟) brownish-green, and (𝔠) bluish-green. The crystals are imperfectly-shaped prisms. A little magnetite and hæmatite are also present.

Slight incipient foliation has been set up in the rock. The diorite

is traversed by the Hatu Pir Granite, and this is itself cut through by dykes of the acid variety of the Hatu Pir Granite already described. The epidote in the diorite is probably due to the contact-action of the granite, as it is particularly abundant along the line of junction, as for instance in a specimen of the diorite in actual contact with a gigantic granite-dyke.

Halfway between Gilgit and Nomal a bed of limestone, 30 feet thick, occurs in a very fine-grained, slaty-looking, micaceous hornblende-schist. One of my specimens is a white crystalline saccharoidal rock; another is streaked with thin cherty and siliceous bands, the latter having a micro-tessellated structure. The second specimen contains some hexagonal crystals of graphite of microscopic size.

These limestones are very pure, and contain from 80 to 92 per cent. of calcium carbonate, with about 4 per cent. of magnesium carbonate. They greatly resemble the Nilt-Hini beds described on a subsequent page. The beds here dip inward, and suggested to Capt. Roberts a synclinal fold. Suggestions regarding the age of these and succeeding limestones will be made later on.

Near Nomal a fine-grained mica-schist becomes the predominant rock. Whole cliffs at that locality are made up of this schist. It is composed of quartz and mica, a little iron-pyrites (the latter mineral is very abundant in Jutial Nalah), red ferrite, and magnetite. The mica is nearly colourless in transmitted light, and its dichroism is scarcely noticeable in thin slices. Quartz-schist also occurs at Nomal, and much of it is reddened with ferric oxide.

Between Nomal and Chalt an epidotic hornblende-schist is the predominant rock. It is composed of bands of hornblende and epidote. The hornblende is orientated indifferently in all directions, and is in long lath-shaped prisms and idiomorphic octagonal cross-sections, set in a quartz-mosaic matrix. The pleochroism is strong: (𝔞) brownish-green, (𝔟) greenish-yellow, and (𝔠) bluish-green. The hornblende- and epidote-crystals penetrate one into the other, sometimes the one and sometimes the other mineral being the intruder, suggesting a contemporaneous origin. The true explanation, however, is probably that a recrystallization of both minerals took place, after the formation of secondary epidote, under the influence of contact-metamorphism.

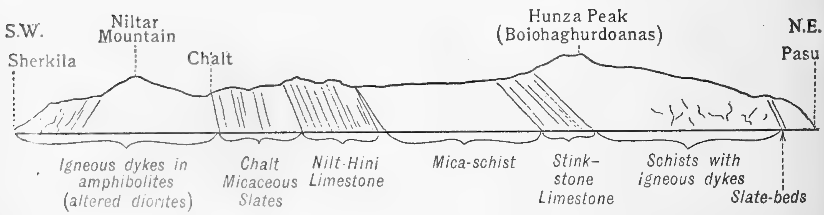
The diorite and hornblende-schists between Gilgit and Chalt have been riddled in all directions by numerous dykes and veins of granite, which form a complete network, the intruders being the normal and acid varieties of the Hatu Pir Granite. The metamorphism produced by this profuse invasion of granite has been intense. Whether or not the hornblendic rocks and schists had suffered any metamorphism prior to the intrusion of the granite I cannot say. The contact-action of the granite, and its accompanying diorite, is sufficient to account for the fairly uniform metamorphism of the hornblendic rocks and schists; and in the absence of any evidence to prove prior metamorphism such previous metamorphism cannot be assumed. Capt. Roberts writes:—'The

whole hillside is intersected in every direction by the granite. I imagine, therefore, that the metamorphism is pretty complete, as there does not appear to be any difference between the rock near the dykes and that far away.'

Between Nomal and Chalt a dark variety of the Hatu Pir Granite —the darker colour being due to the abnormal size of the biotite-flakes—is cut by a diorite composed of well-crystallized hornblende set in plagioclase-felspar with epidote, magnetite, pyrite, a little hæmatite in microscopic grains, and chlorite as secondary minerals. The hornblende is in long lath-shaped prisms, the cross-sections of which are fairly idiomorphic. It is pleochroic in green, greenish-yellow, and bluish-green tints. This diorite, which cuts the granite, is also cut by it.

At Gwech a quartz-rock occurs, which is here and there coloured green by the deposition of chlorite. It is followed by chlorite-epidote-felspar schists which I believe from the microscopic evidence to be altered lavas, and by a tremolite-schist. These are succeeded by quartz and by a ferruginous calc-schist: the last-named rock contains 59 per cent. of silica, 8 per cent. of iron, and about 33 per cent. of the carbonates of iron, lime, and magnesia.

Fig. 1.—*Diagrammatic section from Sherkila on the Yasin River to Pasu on the Gilgit River.*



What I regard as altered volcanic rocks need a few words in passing. One specimen contains chloritic pseudomorphs after idiomorphic felspars. The groundmass, tinged green with chlorite, was probably felspathic to begin with, and it still contains countless colourless microliths suggestive of the felspar-microliths of certain lavas: they cannot be chlorite, as they extinguish at an average angle of $11\frac{1}{2}°$. A second specimen bears a still closer resemblance to a lava, for the felspar-phenocrysts are comparatively unaltered and still exhibit plagioclase-twinning. The felspar is apparently oligoclase, for the angle of extinction, when fairly symmetrical, ranges from 3° to $12\frac{1}{2}°$, and averages 8°. Both specimens contain numerous grains of calcite and epidote, indicating the operation of aqueous agents.

At Chalt slaty rocks come in. They are bluish-grey, have a micaceous glaze, and split readily under the hammer. One of the specimens is calcareous, and is veined with quartz.

At Nilt three beds of white saccharoidal limestone, or marble, come in. 'The valley here,' Capt. Roberts writes, 'runs almost down the line of strike [roughly east-and-west], and the dip is about 70° or 80°. Two beds are seen in the cliffs on the north or Hini side of the river (right bank) and one thick bed on the south side. The latter is below the two Hini beds, and is separated by the width of the valley—say $\frac{1}{2}$ mile.' The beds are broad, well-marked, and their course can be traced across the Minappin River, striking towards the top of a mountain in Fakkar called by Sir Martin Conway the 'Growling Peak.'

The Nilt-Hini Limestones are white crystalline granular limestones not distinguishable from the Gilgit-Nomal bed already described. They are very pure; one, examined chemically, contained a little over 73 per cent. of calcium carbonate, and a little over 24 per cent. of magnesium carbonate. Another specimen contains numerous liquid cavities with movable bubbles, probably due to the contact-action of the neighbouring granite.

Between the Minappin and Tashot, and for some miles up the Minappin, a dark micaceous slaty rock occurs, and is succeeded between Tashot and Askurdas Bridge (over the Hunza River) by micaceous quartzose schists. All my samples contain two micas—a biotite like that of the Hatu Pir Granite and a colourless mica. Both are intergrown in such a way as to suggest contemporaneous crystallization, and the microscopic evidence negatives the supposition that the colourless mica is blanched (decomposed) biotite. One slice is very felspathic and also contains microscopic garnets, magnetite, epidote, ferrite, and large flakes of muscovite. The micas are bent, and exhibit undulose extinction. I think that the slices represent a sheared vein of granite in a sheared quartz-mica-schist.

From Askurdas Bridge to Nagar a muscovite-granite comes in, which I have described in the first part of this paper under the name of the Askurdas Muscovite-Granite (p. 343).

Baltit (Hunza of many maps), and the country around, is composed of the Baltit Hornblende-Granite already described (p. 340). At Baltit it is invaded by the Hatu Pir Granite, and pierced by dykes and veins of it running in all directions. Mispickel is found in the neighbourhood of Baltit, and orpiment and realgar seem to be plentiful in the Irshád and Gujhál valleys. Arsenic is the favourite poison in Northern India, and the Hindu Kush offers an abundant supply. Schorl and perfectly pellucid rock-crystal are abundant at Hunza.

At Altit[1] beds of highly crystalline white limestone, locally termed stinkstones, come in. They have been bleached white, rendered highly crystalline, and powerfully metamorphosed by the contact-action of granite; and to this action the presence of the

[1] Baltit (Hunza) is about $1\frac{1}{3}$ miles above the river. Altit is below Baltit on the right bank of the Hunza river. The sketch-map (p. 344) is on too small a scale to show both places.

following minerals is doubtless due: namely, graphite in lustrous hexagonal tabular crystals, a pink mica, and magnetite. The two former are abundant.

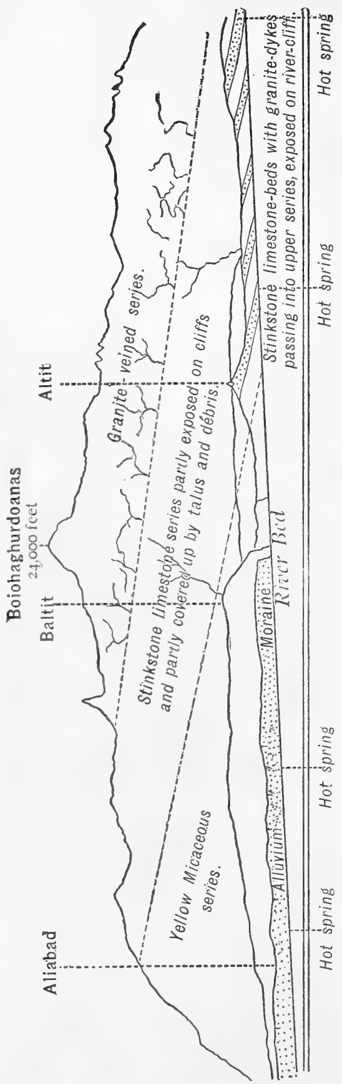


Fig. 2.—*Diagrammatic section through Altit, Baltit, and Aliabad.*

These limestones also contain a silvery mica, chlorite, ferrite, pyrite, and quartz; all of which, with the possible exception of the silvery mica, appear to be due to subsequent aqueous action. Hot springs are numerous in this series.

The limestones are very pure.[1] They dissolve completely and readily, with brisk effervescence in dilute hydrochloric acid, and some that I analysed contained calcium carbonate 96·08, magnesium carbonate 1·93, and iron 1·99 per cent. When struck with a hammer or rubbed together the limestones smell of sulphuretted hydrogen, which seems to indicate the original presence of organic matter. The gas generated from it is still retained in the pores of the rock.

Capt. Roberts informs me that the stinkstones in this section occur in a series of about twenty beds intercalated with mica-schists. Each bed is from 20 to 30 feet thick, and is made up of a central band of solid limestone, with innumerable thin beds of limestone, varying from 1 to 12 inches in thickness, on both sides of the central band.

The whole twenty beds, with their intercalated mica-schists have, Capt. Roberts informs me, roughly speaking a thickness of 2000 feet. The strike is east and west, and the dip about 70° south. The stinkstones crop up again about 8 miles

[1] Some specimens are streaky-looking, from the segregation of the contained minerals.

west of that above described, high above the zone of cultivation in the Hunza Valley. The accompanying diagrammatic sketch (fig. 2, p. 352), kindly made for me by Capt. Roberts, shows the mode of occurrence of the Altit Beds. The true dip is higher than that shown in the sketch.

'On the march from Altit to Gulmit,' writes Capt. Roberts, 'one goes east along the limestone-series, then turns north across the strike and on to the gneiss-series. The hills passed on the right bank are covered with numerous pinnacles and cathedral-rocks, of which the Hunza Feathers[1] are a part. There are some six hot springs (temperature about 90°) issuing from below, or among, the lower beds of the stinkstone in a distance of some 16 miles. This water does not smell of sulphuretted hydrogen, but seems to contain alkaline salts, as in one spring, where it is more abundant than in the others, the incrustation deposited is used by the country people to wash their clothes with.' The sample sent me consisted of magnesium sulphate (Epsom salt).

I have made a microscopical examination of the schists intercalated with the stinkstones between Altit and Ata-abád. They are mica-schists composed of quartz, felspar, biotite, magnetite, garnet, a little sphene, and epidote. In one specimen the felspar is comparatively fresh, and, judging by the extinction-angles, is in part andesine and in part oligoclase. In the second specimen the felspar is so altered as to be almost unrecognizable, and the garnets are flattened and drawn out in the direction of the schistosity. The quartz still contains gaseous and liquid cavities with bubbles. The first specimen contains, in addition to other minerals, hornblende and calcite.

The two specimens just described represent, I think, sheared granites of the Baltit Hornblende-Granite type. They might belong to a very early eruption, or to an early phase of the Baltit Granite-eruption itself. The Baltit rock is the oldest granite in the district, and it was, as we shall see below, undoubtedly erupted into the stinkstones. These particular sills were, I should imagine, intruded into the stinkstones during the earliest phase of the eruption.

I do not regard the alternative hypothesis, that these schists represent sheared arkoses, as probable. It does not seem at all likely that fragments of granite unmixed with other detritus were carried out to sea, and deposited at a spot where very pure limestones were being laid down.

I now pass on to allude to the granites that invaded the stinkstones at a later phase of the eruption, presumably after the crumpling up of the limestone-beds, and contributed so largely to their metamorphism. 'Another interesting feature of this series' [the stinkstones], Capt. Roberts writes, 'is that it has been pierced by dykes of granite that pass through the limestone-beds and spread themselves in innumerable veins and dykes in the series of rocks lying above the limestones.'

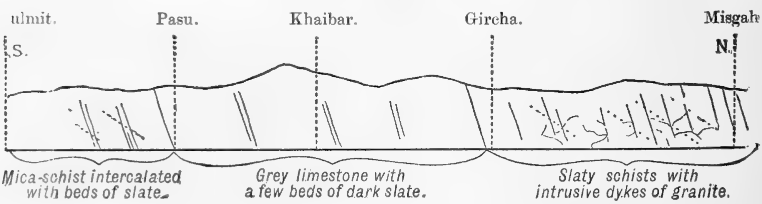
The first to be mentioned is the Baltit Hornblende-Granite. It

[1] See Conway's 'Climbing & Exploration in the Karakorám Himalayas' (1894).

appears as a thick sheet in the stinkstones at Altit and in massive outcrops. Most of the cliffs between Ata-abád and Gulmit are composed of it, and the road between these places runs through it nearly the whole way. Next we have our old friend the Hatu Pir Granite. A dyke of this, 6 feet wide, cuts obliquely across the crystalline limestones, intrudes into the Baltit Hornblende-Granite, and runs a course through it parallel to the line of strike. The third intruder in the stinkstones is the Askurdas Muscovite-Granite, which occurs as a sheet 10 feet thick. The fourth invader is an aplite which runs in small veins through the stinkstones.

About 3 miles south of Ata-abád the stinkstone series ends, and is succeeded by massive mica-schists, which have been so profusely invaded and metamorphosed by the granite that no trace of their strike or dip can be made out. The granite, as above mentioned, runs right through the stinkstones and their intercalated mica-schists (sheared granites), and spreads out in the overlying schists. The granite has not obliterated, or masked, the bedding of the stinkstones; but, owing probably to the greater fusibility of the schists, it has destroyed all trace of bedding in them, and the whole mass of granite and schist is now traversed by joints like an igneous rock.

Fig. 3.—*Diagrammatic section of Gujhál rocks, from Gulmit to Misgah.*



These massive, granite-invaded schists extend for about 15 miles, and at Gulmit they pass into mica-schists intercalated with beds of slate which are sufficiently good to be used as roofing-slates. These beds dip northward, and strike east and west across the valley.

At Pasu (see Capt. Roberts's diagrammatic section, fig. 3) grey limestones succeed and extend, with a few beds of dark slate intercalated with them, as far as Gircha. I shall in the following pages refer to these under the name of the Gujhál[1] Limestones.

'When we left,' my son writes, 'the metamorphosed gneiss and schists, with its granite at Pasu, we found ourselves among mountains of limestone lying at about the same angle [that is, nearly vertical] and striking also east and west. This limestone is many miles in thickness, and forms whole ranges. Here and there

[1] The main valley of the Hunza River running northward from Gulmit is called Gujhál. See p. 140 of Col. A. Durand's 'Making of a Frontier,' 1899, a work that contains good descriptions and beautiful views of the Gilgit cenery.

beds of slate, sometimes as much as 500 feet thick, are intercalated with the limestone.'

These limestones differ considerably in appearance, both in the field and in hand-specimens, from those previously described. They are compact in structure, pale bluish-grey, and weather cream-colour. One that I analysed contained 57·09 per cent. of calcium carbonate; 42·65 of magnesium carbonate; and ·26 per cent. of iron: it is, therefore, a dolomite.

One of the specimens is a fine-grained breccia. Whether the brecciation is due to dynamic causes, or represents detritus formed at the foot of a coral-reef, I cannot say. Under the microscope the specimens are finely granular in structure, and this fine granulation is also seen in the fragments that make up the breccia. The rhombohedral cleavage is well seen in all the specimens, but twinning is rare.

The specimen of the intercalated slate examined is a mylonite-slate with a micaceous glaze on its surface. Under the microscope the slice is seen to be composed of dark patches and streaks, in a colourless groundmass consisting principally of fine grains of quartz, often exhibiting micro-augen structure. The dark patches are composed of magnetite, iron-pyrites, limonite, and carbon. The dark colour of the rock is mainly due to the last-named substance. A few grains of schorl and flakes of mica are scattered through the slice.

The grey limestones end at Gircha, and are followed by slaty schists veined by granite as far as Misgah. At Misgah very fine-grained micaceous grits come in. The grains are subangular, and have not travelled far. They are composed mainly of quartz, but fragments of triclinic felspar are also present. The mica is colourless, and looks like a secondary product resulting from the metamorphism of the interstitial mud. The slice contains a little schorl and apatite, and numerous dots of ferric oxide. The grit seems to have resulted from the erosion of some old granite.

Between Misgah and the Kilik Pass the beds are vertical, and are traversed by numerous dykes of granite. The samples sent me prove to be the Baltit Hornblende-Granite.

My last specimen from this section comes from the top of a peak, 18,000 feet high, at and above the Kilik Pass, looking down on the Taghdumbash Pamir. It is a fine-grained slaty micaceous grit. The matrix is siliceous, with flakes of a greenish-brown mica and ferrite disseminated through it.

At the top of the Kilik Pass, the water-parting between the Pamirs and India, the dip is nearly vertical, with a slight dip to the south.

The study of the grits between Misgah and the Kilik Pass under the microscope at once suggested that I had passed into a younger series, and the same view occurred to my son in the field. He also noted the striking change which the softer rocks introduced into the aspect of the country. 'These loose grits,' he writes, 'explain the formation of the flat Pamir valleys, and the easy slopes and rounded tops of the ranges which fringe them, so different

from the precipitous craggy ranges and deep narrow valleys south of them.'

(6) Gilgit to Yasin and the Darkot Pass.

Between Gilgit and Gupis the strike is hard to determine precisely, as it is very wavy and the rocks are much jointed: it appears, however, to be somewhat south of west. The dip varies from 60° to 90°.

Proceeding in a north-westerly direction from Gilgit up the Yasin River, the foliated diorite of Gilgit passes into a very fine-grained schistose diorite which is well seen in a cliff at Hinzal, 10 miles west of Gilgit. It is a dark-grey compact rock and very fine-grained under the microscope. It is composed of hornblende, biotite, and magnetite. The groundmass consists of granular water-clear felspar.[1] I think that it is only a variety of the Gilgit diorite.

At the 12th milestone west of Gilgit a bed of white crystalline limestone, 30 feet thick, striking east and west and dipping 80° northward, crops up. This is evidently the continuation of the bed between Gilgit and Nomal already described (p. 349). It is nearly due west, and on the exact line of strike, of the Gilgit-Nomal outcrop.

The Baltit Hornblende-Granite comes in again at Bágu, 18 miles from Gilgit. Capt. Roberts sent me three specimens from a cliff opposite Bágu, and my son two from Bágu itself.

From a cliff on the right bank of the river, opposite Sherkila, 23 miles west of Gilgit, I have five specimens of amphibolites which may be shortly described as intensely altered diorites. They are composed of hornblende, felspar, epidote, biotite, apatite, iron-ores, and a little calcite. Two of these specimens have passed into the condition of microgranular schists, but in the others the original structure of diorite can be made out. Phenocrysts of hornblende are present in all, and in one of them porphyritic plagioclase-felspars set in a felspathic groundmass can be seen. In three specimens the felspar of the groundmass is orthoclase. The hornblende has to a large extent been converted into granular epidote and biotite, and the plagioclase-phenocrysts into matted masses of silvery mica, epidote, and zoisite. The original zonal structure can be traced in them, and in some the alteration is confined to the more basic central zones. The least changed of the hornblende-crystals are anything but fresh, and polarize feebly.

An interesting complex of highly-altered rocks is found in a cliff called Gaisheli, a few miles farther up the river, between Sherkila and Gich. The first of these is an altered diorite, in which the phenocrysts are oligoclase. They are not unfrequently broken, showing that the rock has suffered from strain and pressure.

Three of the specimens are epidotic hornblende-schists, which do not differ essentially from the rocks associated with the Sherkila altered diorites just described. Apatite is absent, however, while quartz is added to the groundmass, and in two specimens

[1] When tested in converging polarized light the grains proved in every case to be felspar, and not quartz.

takes the place of felspar. Another sample contains magnetite and pink garnet, in addition to the other minerals. All have suffered greatly from pressure.

Five of the specimens from the same cliff (Gaisheli) appear to be shattered and sheared granites. In two of them the quartz and felspar have been sheared into lenticular strips, and the felspars and muscovite form eyes, and end in strings of silvery mica. The other slices show more or less marks of crush and shearing.

One specimen is a coarse-grained quartz quite free from signs of crushing, and is probably due to the infiltration of heated siliceous water after the earth-movements which disturbed this region had subsided.

A cliff east of Gich (30th milestone west of Gilgit) contains schistose epidiorites which do not call for detailed description. At Gich itself the Hatu Pir Granite and a mica-schist come in. The former gives evidence of pressure, but none of shearing, and there is no approach to parallelism of structure. A cliff farther on, immediately east of Singal (35 miles west of Gilgit), yielded four samples of fine-grained dark grey amphibolites.

At Soma (Suma), at the 56th milestone from Gilgit, compact greyish-white to cream-coloured calcareous rocks come in. They are somewhat hard under the knife. The microscope shows them to be microgranular in structure, and they contain grains of calcite scattered through them. The analysis of one sample showed that it contains 75 per cent. of silica, and about 20 per cent. of calcium carbonate, with a little of the carbonates of iron and magnesia. Capt. Roberts thinks that these beds represent the Nilt-Hini Limestones of the Gilgit-Kilik Pass section, as he found beds corresponding to the Nilt–Hini Limestone in the intervening valley of Ashkurman, to be described on p. 358. I think myself that the beds more probably represent the calc-schist near Gwech, already described (p. 350). Soma and Gwech are on the same line of strike, and are at a somewhat lower horizon than the Nilt-Hini Beds. Moreover, the Soma rocks are compact, while those of Nilt-Hini are pure crystalline calcite.

Between Gukuch and Gupis the following succession is observed:—Mica-diorite; the Baltit Hornblende-Granite; amphibolites. Two of the amphibolites are micaceous as well as hornblendic. One shows the junction of two kinds of rocks. In one biotite is very abundant, and it appears to have passed over by diffusion into its neighbour, the biotite becoming less in amount as the distance from the micaceous rock increases. The other shows strong parallelism in the orientation of the hornblende, and contains a little biotite. The amphibolites are all dark-grey compact rocks, and one of them, macroscopically considered, might almost pass for a basalt. Magnetite is abundant in some of them: it is sometimes idiomorphic.

Upon the amphibolites follows a rock which I hesitate to call definitely an ash, but it has somewhat the appearance of one. It is fine-grained, contains fragments of many different kinds of rocks,

quartz (by no means the most abundant material), fragments of plagioclase-crystals, felstones, rhyolitic lavas, quartz-porphyries, and other acid rocks, as well as magnetite and splintery fragments of calcite. The fragments in this rock are angular to subangular, some being plainly splinters with sharp points and edges.

The Baltit Hornblende-Granite succeeds the ash-like rock.

My next specimen is a red sandstone from a cliff at Yasin. The grains are for the most part subangular: none are waterworn. They consist of quartz, siliceous rocks, and grains of magnetite, but none are recognizable as igneous rocks. The specimen is very much stained with ferric oxide.

At the mouth of the Tui River a quartzite weathering reddish and a slaty-looking sandstone occur in alternate layers a few feet thick. They have both suffered from pressure and from metamorphism. The quartzite is a peculiar rock: some of the quartz-grains have a micro-tessellated structure, and the larger grains exhibit undulose extinction. Some of them are fragments of plagioclase, others are microcline. Possibly this rock may represent the siliceous apophyses of a granite greatly crushed.

At Barkulti, 15 miles south of Darband, Capt. Roberts discovered a bluish-grey limestone more like the Gujhál Limestone than the Nilt-Hini marbles or the stinkstones. It has a thickness of about ½ mile.

At Darkot a compact grey limestone comes in, which both my son and Capt. Roberts identify as the grey limestone of Gujhál. One of these specimens contains 64·40 per cent. of calcium carbonate and 34·07 of magnesium carbonate, but the other yields 63·88 per cent. of siliceous matter and only 32·47 of calcium carbonate, showing how greatly the beds contained in these limestones vary in chemical composition.

The Hatu Pir Granite comes in above the Darkot Limestone. It does not exhibit parallelism of structure, but it has suffered considerably from pressure. A sandstone also occurs above the Darband Limestone.

The succession from the Gujhál Grey Limestone up to the top of the water-parting which separates the Pamirs from the Gilgit area is thus the same both in the Darkot-Pass and Kilik-Pass sections. The compact and comparatively unaltered limestones are succeeded by sandstones and grits of apparently younger age. In both cases granite is an intruder in them, being, in the case of Kilik, the Baltit Hornblende-Granite, and in the case of Darkot the Hatu Pir Granite.

(7) The Ashkurman (Ishkumman) Valley.

Capt. Roberts very kindly undertook the exploration of this valley, which runs northward to the Pamir, halfway between the Yasin-Darband and Gilgit-Kilik valleys, for the purposes of the present paper.

The succession of rocks in this valley, commencing at its mouth and proceeding northward, is as follows:—

A dark grey schistose slaty rock, dipping about 75° northward, and striking west by north and east by south.

About 2 miles up the valley two beds of limestone, close together, the southern being 50 and the northern 100 feet thick, cross the valley with the same strike as the schistose slaty rocks. I have three specimens. Of these one is a white crystalline limestone; another is a bluish-grey chert, with fine quartz-veins; and the third is a grey-and-white streaky limestone containing quartz.

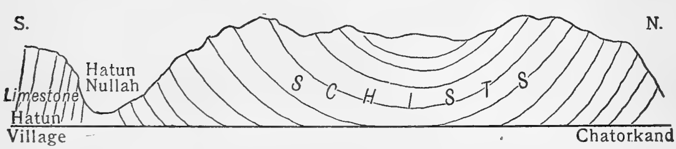
One mile farther on, near the village of Hatun, a third band of limestone, 400 feet thick, with which thin schistose beds are intercalated, crosses the valley, dipping vertically, and with the same strike as the other beds. I have four specimens of this band. They are all compact in structure, the first two and the last are white, and the other bluish-grey. One of the specimens is slabby, with silvery mica on the splitting surface.

Capt. Roberts thinks that these three outcrops of limestone, which he calls the Hatun Series, represent the Nilt-Hini Beds of the Gilgit Valley. There also, it will be remembered, the beds are three in number (p. 351).

The Hatun Limestones are succeeded by a thinly-bedded calciferous slaty rock, with which is interbedded an altered ash. The ash contains numerous fragments (large and small) of plagioclase-felspar.

Between Hatun and Chatorkand, a distance of about 9 miles, a bluish-grey micaceous slate, which reminds me very much of some rocks of the Simla area,[1] occurs, sparsely interbedded with a chloritic epidotic fissile rock that looks like a very fine ash.

Fig. 4.—*Diagrammatic sketch of anticlinal fold between Hatun and Chatorkand.*



Capt. Roberts sends me a sketch (fig. 4) of an anticlinal fold which is well seen on the west side of the valley, between Hatun and Chatorkand. The centre of the fold is very distinctly marked.

About 2 miles north of Chatorkand two beds of limestone, at an interval of 1 or 2 miles one from the other, cross the valley with approximately an east-and-west strike. They dip about 70° northward, and the two hamlets, Pakor and Shenas, 'lie on or near their strike.' The micaceous schists in which they lie are paler and more finely laminated than those associated with the Hatun Series. The schists and limestones are regularly bedded, and no contortion has taken place. No granite-dykes are to be seen in this section. The Pakor limestone is about 30 and the Shenas limestone about 100 feet thick.

[1] For instance, the bluish-grey micaceous slates at Dalhousie, on the cart-road below Balun.

I have received the following specimens from Pakor:—a cream-coloured, compact, very pure limestone, and a white crystalline, very pure limestone. From Shenas:—a dirty-white calcareous quartz-rock; and a bluish-grey, compact, magnesian limestone. The last-named specimen contains a trace of iron, but the colouring-matter consists of 0·102 per cent. of amorphous carbon. The bulk of the rock is made up of calcium and magnesium carbonates.

About 1 or 2 miles farther on, at Barjagal, bluish-white to cream-coloured quartzites, with a silvery micaceous glaze on the splitting-surfaces, come in, with the same strike and dip. They are followed near Imit by a siliceous ferruginous rock and a dark carbonaceous slaty rock containing numerous flakes of mica, red in transmitted light. A biotite-gneiss follows, with intrusions in it of a granulitic biotite-muscovite-granite, which appears to be the Hatu Pir Granite.

Beyond Imit a granite-dyked series crops up. The sample of this granite that has been sent to me proves to be the Baltit Hornblende-Granite. These intrusive dykes are so numerous, and they have so completely altered the rock into which they intruded, that the whole weathers and joints as an igneous rock. The intrusion has produced a remarkable change in the character of the scenery, rugged peaks and sharp ridges giving way to rounded granite forms.

The Gujhál Grey Limestone does not occur *in situ* between Imit and the moraine of the Karumbar Glacier, but blocks of it are scattered in the river-bed, showing its presence higher up the valley.

Part III.—Conclusion.

From Astor, on the extreme south, to Gilgit, the rocks are mainly of igneous origin, and they are split up by irregular joints, which have been mistaken by some observers for dip-planes. From Gilgit northward to the Kilik Pass, leading to the Taghdumbash Pamir, the strike of the rocks is approximately east-and-west, and my son observed that the mountain-ranges run more or less in the same direction; as, for instance, the Rákapushi, Boiohaghurdoanas, Irshád, and Kilik ranges. The direction of the strike, however, has not exercised a predominating influence on the course of the principal rivers. The Indus, indeed, has an easterly-and-westerly direction through a considerable part of the Gilgit area,[1] and the Hunza River runs more or less in a westerly direction from Ata-abád to Chalt. But the Indus, from its junction with the Hunza, runs as far as Ramghat; and the Hunza, from the Kilik until it flows into the Indus, with the exception of the portion above mentioned, runs across the strike of the rocks in a southerly direction.

If we consider the lofty character of the mountain-ranges which rise in peaks ranging from 20,000 to nearly 27,000 feet above sea-level, and the fact that those on the northern boundary of Gilgit

[1] It resumes, and continues for a long distance, a nearly southerly course before leaving Gilgit.

form the water-parting between Central Asia and India, this tendency of the principal rivers of Gilgit to run across the strike of the rocks appears to imply that the direction of the main drainage of the country was determined before, or at the commencement of, the last series of earth-movements that threw the strata into a series of east-and-west folds, and compressed them together until they assumed a monoclinal and vertical dip. It also shows that the process of folding and compression was slow and gradual, and that it did not exceed the rate at which the river-beds were then being eroded.

In the topographical part of this paper I restricted myself to a bare description of the numerous outcrops of limestone which occur in the Gilgit area. I desire now to explain my views regarding their age.

No fossils have been found in the Gilgit limestones, and I doubt whether any will reward those who search for them. The profuse intrusion of granite and other igneous rocks in this area, and the profound alteration of the sedimentary rocks caused by their contact-action, must have destroyed all the fossils. In the neighbouring district of Kashmir, however, the great conformable series of limestones known to Himalayan geologists as the Carbo-Triassic Series are abundantly fossiliferous, and the Triassic beds can there be separated from the underlying Carboniferous Limestones.

The Carboniferous Limestones of Kashmir are shown in the map appended to Mr. R. Lydekker's paper in the Records of the Geological Survey of India, vol. xiv (1881) p. 56, and in that attached to his Memoir on the Geology of Kashmir [1] a little to the north of Shigar (see sketch-map, p. 344) in contact with the Triassic Series. The two outcrops there vary from 5 to 15 miles in thickness. In the map published with the 'Manual of the Geology of India' 2nd ed. (1893), the united outcrop is coloured 'Carboniferous to Trias.' Its course is shown to be from Shigar to the east of Askole, and thence along the western side of the Biafo Glacier towards the end of the Hispar Glacier.

Prof. Bonney & Miss Raisin's description of Sir Martin Conway's specimens enable me to connect the Biafo-Glacier outcrop with the 'stinkstones' of the Hunza Valley in Gilgit. I leave out of count Sir Martin Conway's specimens from the Biafo Valley, the Baltoro Glacier, and the Golden Throne, though they are interesting and show the extension of the Askole–Biafo outcrop into Kashmir on an east-and-west strike. Other exposures are of more importance to my present purpose. Prof. Bonney describes specimens found *in situ* between the Hispar Glacier and Tashot on the Hunza River, namely, limestone-breccia along the Shallihuru Glacier (one of the affluents of a river flowing from Hispar to Nagar); also crystalline limestones *in situ* on the Rash ridge, and in the Samaiyar Valley south of Nagar.

Two or three beds of marble, 20 feet thick, which are said to occur between Tashot and Fakkar are undoubtedly the eastern

[1] Mem. Geol. Surv. Ind. vol. xxii (1883).

extension of the three marble-beds of Nilt-Hini described on p. 351 of this paper. Some limestone-specimens were also collected by Sir Martin Conway in the Bagrot Valley, which doubtless represent the eastern extension of the bed between Gilgit and Nomal.

Col. Godwin-Austen, F.R.S., informs me that when in Kashmir he traced the Carbo-Triassic Series up to the top of the Nushik Pass; and Capt. Roberts tells me that the valley running up from Hunza to the Shimshal Pass, looked at from the Hunza side, appears to be all limestone.

The limestones of the Gilgit-Kilik section extend in a westerly direction into the Yasin and Ashkurman Valleys, and my son informs me that they crop up still farther west at Chitral and also in the Bimborit Valley (Bumboret of Curzon's map) which runs into the Chitral Valley from the west above Kala Drosh. In the Bimborit Valley bluish-white limestone and slate, both resembling those of the Gilgit-Kilik section, 2 or 3 miles wide, occur, dipping vertically and associated, as usual, with granite.

I also note that Mr. C. L. Griesbach, C.S.I., now Director of the Geological Survey of India, in his geological map of Afghanistan, records an extensive outcrop of the Carboniferous and Permian rocks between Jellalabad and Kabul, and again to the north and north-west of Kabul. Both these outcrops, like those of Gilgit, are much invaded by masses of granite.[1]

As this great conformable series has been identified in the Kashmir Valley by competent geologists up to the borders of Gilgit; as it can be traced from the borders into Gilgit; and as it reappears on substantially the same strike on the other side of Gilgit in Afghanistan, I think I may venture to claim the Gilgit Series as identical with the Carbo-Triassic Series of the North-western Himalaya.

Several of the Gilgit rocks are remarkably like some of the Himalayan rocks. For instance, the bluish-grey micaceous slate between Hatun and Chatorkand (p. 359) could be matched by specimens at Dalhousie on the cart-road below Balun. The white quartzite at Barjagal, with a micaceous glaze on it (p. 360), is not distinguishable lithologically from the milk-white Krol quartzite in the Satlej Valley at Nogli.

There are other points of resemblance. In the North-western Himalaya, and in Kashmir, a volcanic series comes in at the top of the Silurian and the lower part of the Carboniferous Series; and there is some evidence to show that similar rocks occur in the Gilgit area at approximately the same horizon. What appear to be altered volcanic rocks are found below the Nilt-Hini marbles (p. 350), and ash crops up in the Yasin section (p. 357) and in the Ashkurman Valley (p. 359).

Capt. Roberts's description of the 'stinkstones' at once brought forcibly to my mind the Krol Series of the Simla area. In the matter of colour, however, there is a great difference. The Krol

[1] Rec. Geol. Surv. Ind. vol. xx (1887) p. 93.

limestones are dark bluish-grey—the Gilgit limestones are for the most part white. Nevertheless, this difference does not appear to me to be material. The Krol limestones are not invaded by granite, whereas the Gilgit limestones are profusely intruded by this igneous rock and the contact-metamorphism has been most intense. One of the limestones of the Ashkurman Valley (a compact unaltered rock not invaded by granite) is bluish-grey—this coloration being due to the presence of 0·102 per cent. of amorphous carbon (p. 360). In the other Gilgit limestones the contact-action of the granite by which they were invaded caused a segregation of the iron and carbon contained in them into magnetite and graphite, and thus restored the carbonate of lime to its natural whiteness. Even in the Simla region I came across white limestone on the flank of the granite-mass of the Chor Mountain.

In the Gilgit area the first outcrop of the limestones is between Gilgit and Nomal, and the last is at Gircha, the distance across the strike being about 47 miles. I need hardly say that I do not regard the successive outcrops, presented to us in this section, as members of an ascending conformable series. Many considerations lead me to believe that we are dealing here with a compressed series of folds. The same beds have, I believe, been repeated again and again, and a delusive appearance of great thickness and regular succession created by monoclinal folding.

The saccharoidal limestones of Gilgit-Nomal and of Nilt-Hini I consider to be beds on the same, or about the same, horizon. Differences in the thickness or number of the beds are probably due to local variations in the conditions of deposition. The Altit 'stinkstones' probably belong to a slightly higher horizon. They occur only in this section, and either thinned out westward, or were pinched or faulted out in the intense compression and folding that took place. The Gujhâl dolomites and limestones differ greatly in appearance, condition, and composition from the limestones referred to above. They belong apparently to a higher horizon, and are probably of Triassic age. Their great thickness in the Gilgit-Kilik section is perhaps due to repeated folding and compression.

That the limestones in the Gilgit area have been crumpled up and repeated in a series of compressed monoclinal folds is, I think, proved by the evidence afforded by the 'stinkstones.' Capt. Roberts assures me—and I made a special inquiry from him, in order that no doubt might remain as to the fact—that the 'stinkstones' are composed of a series of about twenty bands, each of which is made up of a solid central bed of limestone with innumerable thin bands of limestone from 1 to 12 inches thick on either side of it (p. 352). It is not at all likely that so peculiar an arrangement of one thick bed lying in the middle of numerous thin beds would be repeated in the course of ordinary deposition twenty times in succession. It is much more easy to believe that a single composite band, composed of one thick bed in the middle of a number of thin beds, was crumpled up and compressed into monoclinal folds in which the band was repeated by folding twenty times.

If I am correct in correlating the limestones of Gilgit with the Carbo-Triassic Series of Kashmir and the North-western Himalaya, it follows that the micaceous slates, schistose rocks, and grits that lie above the limestones cannot be older than Triassic, and may be of younger age. The metamorphism that they have undergone is slight, and is easily accounted for by the intrusion of granite and by the pressure that tilted them into a vertical position.

It also follows, from this correlation, that the schists below the limestones are presumably of Lower Carboniferous or Silurian age. They have all suffered from great pressure and from profuse granitic and dioritic intrusions, and these igneous intrusions are amply sufficient to account for the metamorphism that they have undergone. Even in the Satlej Valley pressure and the neighbourhood of granite have converted many of the volcanic rocks into hornblende-schists.

I now pass on to offer a few remarks on the age of the eruptive rocks. The oldest granite in this area is the Baltit Hornblende-Granite, but as it is intrusive in the grits above the limestone-series, it must, for the reasons above given, be younger than the Trias.

The next in order of time is the Hatu Pir Granite. It is intrusive in the Baltit Hornblende-Granite, in the limestones, in the foliated diorite of Gilgit, and in the grits of the Darkot Pass. The normal Hatu Pir Granite was followed by the acid variety of this granite. The acid variety is intrusive in the normal Hatu Pir Granite and in the Gilgit diorite.

The Askurdas Muscovite-Granite is intrusive in the limestones, in the Hatu Pir Granite, and in the Lecher Pyroxenite. It seems probable that this rock, as well as the acid Hatu Pir Granite, represents a late phase of the Hatu Pir eruption; indeed, I am disposed to think that all the Gilgit granites emanated from one and the same igneous reservoir, and represent successive stages in its history.

Last of all come the aplites, which appear as veins in the limestone and are probably of Hatu Pir age.

The pyroxenite and diorite of the Gilgit area seem to have been erupted at intervals during the different phases of the Hatu Pir eruption, which apparently occupied a very considerable period measured in years. Thus the pyroxenite between Ramghat and Julipar is intrusive in the Hatu Pir Granite, but is itself traversed by the Askurdas Muscovite-Granite. The diorite also sometimes cuts through granite, and in other places is cut through by granite.

As the oldest granite is intrusive in the youngest rocks of this area, its precise age cannot be determined; all that can be said is that it is of post-Triassic age.

Several of the granites mentioned in this paper exhibit structures,

alluded to in the foregoing pages, which are also observed in the gneissose granite of the Dalhousie region. I have already given my reasons[1] for believing these structures to have been produced by traction at the time of intrusion and by shearing and pressure, operating on the rock during its gradual cooling and progress from a viscid to crystalline condition. I have seen nothing in my study of the Gilgit rocks to modify that opinion.

In the foregoing pages I have given abundant details of dynamic action on the rocks of the Gilgit area, and in particular have noted cases in which granite has been shattered or sheared into shreds, and I am willing to believe that in these cases the shearing may have taken place after the consolidation of the rock. When, however, we are dealing with structures which are not limited to thin sheets, or dykes, but permeate granite-masses 10 to 12 miles thick, the application of the shearing-after-consolidation theory to explain those structures becomes to my mind unreasonable.

In the Gilgit area shearing seems to have been quite local, and confined to the immediate neighbourhood of thrust-planes and faults. For instance, granite-sills and veins in the Gaisheli Cliff have been sheared into lenticular strips of quartz and felspar, while the Hatu Pir Granite hard by (at Gich) does not show any parallelism of structure. Either the Hatu Pir Granite was intruded after the shearing had ceased, or, far more probably, the thrust-plane which caught the granite in the Gaisheli Cliff passed clear of the granite at Gich.

I shall not attempt to go over old ground, but before leaving the subject of structures in granite, such as tessellated quartz, it may be as well to give an illustration from the Gilgit rocks. At Lecher the Hatu Pir Granite is cut through by a pyroxenite, and both are traversed diagonally by the Askurdas Muscovite-Granite. The Hatu Pir Granite shows some ordinary parallelism of structure. The pyroxenite exhibits none whatever, but in the last invader the quartz is tessellated and drawn out into strings. Is it probable, I would ask, that the dynamic force which impressed itself so deeply on the last intruder can have been applied to this igneous complex after its consolidation? If it was so applied, is it conceivable that it should have left the pyroxenite unsheared, unfoliated, unfaulted, and without a trace of parallelism of structure? According to my theory, the case presents no difficulty. The Hatu Pir Granite had a slight parallelism of structure imparted to its biotite by pressure when it was in a plastic condition. The pyroxenite crystallized in tranquil times. The Askurdas Granite welled up into a fissure, the walls of the fissure were moved up and down, and the granite was squeezed between them when approaching consolidation.

The Gilgit granites abound with examples of the s o l v e n t   a c t i o n

[1] A summary account of these structures and of my views regarding them will be found in my Presidential address to the Geologists' Association, Proc. G. A. vol. xiv (1896) p. 287.

of quartz[1] upon the other minerals during a later stage in the history of the eruption. This action was probably due to a combination of two causes:—firstly, the gradual silicification of the residual magma due to the crystallizing-out of the more basic minerals; and secondly, the increase of heat due to friction and compression caused by the forcible injection of a viscous and partly crystallized granite into fissures and faults, or between strata, in the form of sills, laccolites, or dykes. The increase of heat increased the solubility of the crystals already crystallized, and enhanced the solvent power of the acid silica in the liquid magma.

A study of the Gilgit granites in thin slices under the microscope shows that the quartz of these granites, during its corroding stage, ate into the other minerals, especially the felspars and biotite, simultaneously attacking numerous points of weakness, and appeared in these minerals as small rounded blebs. By gradual increase in size these blebs coalesced and formed lakes, bays, and gulfs in the felspars attacked. This action, combined with a nibbling into the outer edges of the felspars by the quartz, produced in some cases fantastically-shaped skeletons of felspar. In other cases the numerous rounded blebs of quartz in the felspars gave the rock an appearance of granular structure or simulated that of perthite. (See Pl. XXIII, figs. 2–5.)

The granophyric structure, so common in these rocks, is only, it seems to me, an example of the same process in an incipient stage.[2] When the process of resolution set in, and the liquid quartz began to eat its way into the crystals, the felspars yielded (according to my theory) almost simultaneously at many separated points of weakness, and the invading molecules of silica were influenced in the direction which they took by the planes of solution and of cleavage within the crystal. The result was that, when the process of resolution was arrested in its initial stage, the corroding quartz assumed those graphic shapes so commonly seen in granophyre.

Those who have watched crystallization take place from a solution on a glass slide will have noticed that sometimes crystallization begins almost simultaneously at many points separated one from the

[1] This subject was referred to and illustrations were given in my Pres. Addr. Proc. Geol. Assoc. vol. xiv (1896) p. 287.

[2] Several explanations have been suggested by different authors to account for the granophyre in the rocks that they have described. Without challenging the correctness of those explanations as regards the rocks dealt with by those authors, I can only say that I do not think any of them applicable to the Gilgit granites, with the exception of the following:—Roland Irving, in his monograph on the Copper-bearing Rocks of Lake Superior (U.S. Geol. Surv. vol. v, 1883), describes what we should call granophyric structures in augite-syenite and granitell:—'In the larger number of sections,' he writes (p. 113), 'the felspar-crystals are charged also with secondary quartz, which occurs either in rows of club-shaped or graphic particles which often follow the cleavage-directions of the crystals, or in very fine lines radiating in fan-shape from a central line.' He speaks of this secondary quartz as 'quartz-saturation,' and states that 'in many cases it is evident ... that the replacing process has gone on from without, inwards' (p. 114). The author does not tell us, however, how the 'quartz-saturation' is effected, or whether it is an aqueous, aqueo-igneous, or igneous operation.

other. Resolution seems to me to follow a similar course. Wherever a point of weakness presents itself, the corroding liquid begins its inroad. Occasionally residual quartz may be seen actually passing into granophyre: an illustration of one such case is shown in Pl. XXIII, fig. 6.

The causes which led to the formation of the quartz-mosaic so frequently seen in the Himalayan granites were discussed in some detail in my paper already quoted, and need not be repeated. These mosaic structures are equally abundant in the Gilgit granites, and a similar explanation applies to them. Briefly stated, it is that the large quartz-crystals and the felspar suffered partial resolution during the movement of the granite into place, and were penetrated by intrusive veins of liquid quartz. The tessellated structure, according to my view, was imposed on this residual quartz by strain at the moment of its final crystallization. The larger quartz- and felspar-crystals do not exhibit this structure. The quartz-mosaic is not an uniform granular structure pervading the whole rock, but appears in the quartz and felspar more like a granite invading a sedimentary rock.

The structures seen in the shattered and sheared granites of the Gilgit area are quite different in character. In them the quartz and felspar are sheared down into strips.

An interesting question suggested by the study of the Gilgit rocks is whether the intrusion of the granites described took place before, during, or after the crumpling of the sedimentary rocks? The full elucidation of this problem must be left to future observers. The intrusion of the granites evidently occurred during a very extended period, measured in years, and I am disposed to think, from the facts presented in this paper, that the eruption of the Baltit Hornblende-Granite began when the crumpling of the strata was in progress. It is clear that the eruption of part of the Hatu Pir Granite, at all events, must have taken place after the monoclinal folding had been completed, for it cuts obliquely across the limestone-beds (see p. 354). Had these beds been folded, or compressed sufficiently to cause a differential movement of the beds which were in contact, after the intrusion of the granite, the oblique dykes must have been faulted and dislocated. The plication of horizontal beds into a series of folds, and the compression of these folds into monoclinal strata, must have produced a differential movement, or shearing, between the beds that were in contact one with the other, and this movement must inevitably have left its marks on the oblique dykes of granite intruded into the limestones before the movement ceased.

It follows also, if the foregoing conclusion be admitted, that the acid variety of the Hatu Pir Granite and the Askurdas Granite were also intruded after the crumpling of the strata had been completed, for they are both younger than, and are intruders in, the Hatu Pir Granite. This conclusion has an important bearing on the age of these granites.

EXPLANATION OF PLATE XXIII.

[Illustrations of some phases of the partial resolution of quartz and felspar by liquid residual quartz. All the illustrations are reproductions of photographs of slices seen under crossed nicols, made from specimens of Gilgit granite.]

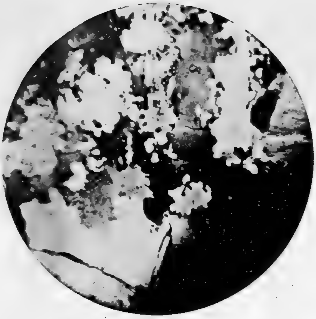
Fig. 1. The amœboid structure of residual quartz. (See p. 342.)

2. Tessellated residual quartz eating into crystals of felspar. (See pp. 366, 367.)
3. Tessellated residual quartz eating into a large quartz of first generation. The lower dark portion of the figure is felspar. (See pp. 366, 367.)
4. Residual quartz eating into felspar-crystals. The dark portions on the right and on the upper left hand of the figure are allotriomorphic felspars corroded by the quartz. The fingers projecting from the hand-shaped quartz on the upper right hand illustrate the tendency of the corroding quartz to avail itself of the structural planes of the felspar. (See pp. 342, 366.)
5. Residual quartz eating into a felspar-crystal, and appearing in its interior as blebs and irregularly-shaped patches. (See p. 366.)
6. Residual quartz passing into granophyre. The dark portions of the figure are felspar; the light portions, quartz. The oval and pear-shaped pendants near the centre of the figure exhibit granophyric structure. This is quite distinct when examined under a microscope with high powers: a 1-inch objective was used for the illustration. The circular white spot at the lower end of the figure is a bleb of quartz in the felspar. (See pp. 366, 367.)

Discussion.

Col. Godwin-Austen said that in 1860 he was deputed by Capt. T. G. Montgomerie, R.E., in charge of the Kashmir Survey party, to survey Baltistan with the plane-table on the 4-mile-to-the-inch scale. In that year and the following he completed the area partly shown on the map exhibited, bounded on the west by the longitude of 75°, and extending from the northern edge of the Deosai Plateau to the ranges and great glaciers at the edge of the Shigar River, his limit on the north-west being the Hispar Glacier; thence eastward along the Mustagh Range, the Baltoro Glacier (until then unknown), the Masherbrum Range, and the Hushè Valley, to the Shayok River and the Indus. While this work was in progress, he had great opportunities for observation of the geology, and he laid down the boundaries of the stratified series. He had always hoped to get back to that part of the world, and to continue the survey to the westward; but in 1862, owing to the illness of another officer of the Kashmir party, he was sent to survey the Chang-Chingmo and Pangkong Lake, far to the east of Ladak. The Author had given him undue credit for having penetrated farther than he did. It was the Nushik La, not the Shimshal, to which he had told him that he had penetrated, the pass crossing over to the Hispar Glacier, which was the nearest point that he reached towards Hunza Nagar. Forty years ago all the country to the west was unknown and unsafe: no European officer had yet been in Gilgit. The most powerful chief in Hunza was Gor Rahman, a name dreaded by his neighbours far and near. The Maharajah of Kashmir had barely obtained a footing in Gilgit, and about this period the Dogra garrison had been massacred to the last man.

Quart. Journ. Geol. Soc. Vol. LVI, Pl. XXIII.



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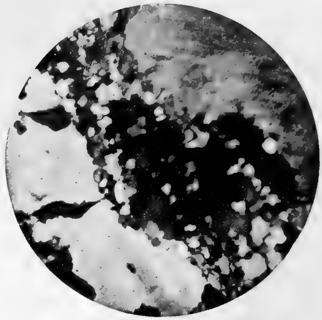

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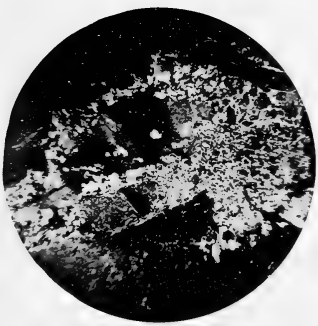

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6.

Gilgit Rocks.

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With regard to the Carbo-Triassic Series, he had formed the conclusion that these rocks were crushed up between the folds of the granite and the metamorphic rocks, occupying distinct long, narrow troughs, or elliptical basins. Thus a great development of this series is to be seen south of Scardo extending to Shigar; in the gorges running from Scardo up to the Deosai plains, magnificent sections are exposed of the great folds into which these rocks have been thrown. This southern band can be followed eastward over the Tusserpola for many miles, and westward across the Indus to the Tormick Valley and the Stok La. A range of granite and the older rocks comes in on the north, but at the end of the Biafo Glacier the same section is repeated, and another belt of the Carbo-Triassic can be followed eastward to the Masherbrum Range and westward along the Braldu Valley to the Chogo Loongma Glacier near Chutrun and Arundo. The high ridge between the last-named glacier and the Hispar is in great part Carbo-Triassic. A third distinct and more northerly band of stratified rocks (but no massive limestone) is met with at the upper sources of the Palma Glacier on its northern side. This lies west of the Mustakh Pass; it was seen to extend westward, and very probably joins the stratified rocks north of the Hispar Glacier in Hunza Nagar. The section on the Baltoro Glacier reminded him in its composition of the rocks met with on the Pir Panjal.

The President and Mr. R. D. Oldham also spoke, and the Author replied.

23. *The* ZONAL CLASSIFICATION *of the* WENLOCK SHALES *of the* WELSH BORDERLAND. By Miss GERTRUDE L. ELLES, of Newnham College. (Communicated by J. E. MARR, Esq., M.A., F.R.S. Read December 20th, 1899.)

[PLATE XXIV.]

CONTENTS.

I. INTRODUCTION.

In Southern Sweden occurs a series of shales of Wenlock age, which Tullberg divided into zones by means of their predominant graptolites.[1] During a visit to that country in the early part of 1896, I was enabled, through Dr. Törnquist's kindness, to spend some time in studying the fauna of these zones, and I determined that when I returned to England I would ascertain whether some such zonal classification did not also hold good for the beds of Wenlock age in our own country.

During the past four years I have studied in detail the strata and the graptolites of the Wenlock Beds of the Welsh Borderland, and I find that such a classification can certainly be made. Further, as the existence of Tullberg's zones[2] has recently been called in question, and doubt has been thrown upon the validity of several of his species, it seems only fair to the memory of that geologist to bring forward the results that I have obtained, which appear to me to confirm his work completely.

A glance at the Geological Survey maps of the Welsh Borderland would seem to indicate that the Wenlock Shales cover a considerable extent of country. This, however, is not really the case: far from being of wide extent, the Wenlock Shales are generally present as a mere fringe below the Ludlow rocks. It is the Ludlows, and particularly the Lower Ludlows, which occupy the greater part of the area. Frequently the so-called 'Ludlow' of the Geological Survey maps of the Welsh Borderland is the equivalent of the Upper Ludlow of the maps of the typical area of Shropshire. The reason for this seems to be, that the Wenlock Shales and Lower Ludlow Beds of the Welsh Borderland are often identical in

[1] 'Skånes Graptoliter' pt. i (1882) Sver. Geol. Undersökn. ser. C, no. 50, p. 15.
[2] Frech & Rœmer, 'Lethæa Palæozoica' vol. i, pt. iii (1897) pp. 650–653.

lithological character, and were naturally mapped as one formation, while the Upper Ludlow is decidedly different in this respect, so the main line of separation was drawn at its base. Nevertheless, the Lower Ludlows may be at the present day readily distinguished from the Wenlock Shales palæontologically, for they contain a perfectly distinct graptolitic fauna.

My own researches have led me to the conclusion that the best palæontological division of these two rock-groups is one which separates

(*a*) A group characterized by graptolites of the *priodon-Flemingii*-type (that is, Wenlock Shales) from

(*b*) A group characterized by graptolites of the *colonus*-type (=Lower Ludlow).

In this opinion I am supported by Miss E. M. R. Wood, who has been working for some time on the fauna of the Lower Ludlow rocks. This classification is certainly of a practical working value; for, as a result of our field-work in many localities, we have both of us always found that the *Flemingii*-fauna dies away where the *colonus*-forms become abundant. I would therefore propose to restrict the term Wenlock Shale to the rocks containing the first of these faunal groups, and the term Lower Ludlow to the rocks containing the second.

The present paper is concerned only with the Wenlock Shales and their graptolitic fauna. My work on these Wenlock Shales has extended over a considerable part of the Welsh Borderland, but I have chosen three special areas for detailed work.

The most important district appears to be that which lies round the town of Builth. There the Wenlock Shales can be studied from base to summit; this area therefore is taken as the typical one. There is no other district along the Welsh Borderland where the rock-succession is so complete and so fossiliferous throughout, though excellent confirmatory sections occur in the two other areas that I have studied, namely, in the Long Mountain and in the Dee Valley. In the Long Mountain, the basal beds of the Wenlock Shales are not seen, while in the Dee Valley the upper part of the series contains but few fossils, and the succession is complicated by the coming in of the grits, which attain a great development farther north.

I have purposely avoided, for the present, those districts where limestones or grits enter largely into the sequence, as my object has been to study the succession of life where the Wenlock Series was most typically developed. Now, the Wenlock is essentially a shale-formation, though locally, as is well known, some of the beds of shale are replaced at different horizons by beds of limestone or grits. Also, in the localities where limestones or grits form an important feature in the succession, the graptolites are fewer in number both as regards genera and species, and a zonal classification will prove to be a matter of greater difficulty.

II. Literature.

The Builth District.

Very little has been written about the Wenlock Shales of Builth, though much attention has been paid to the Llandeilo Beds of that area. The Wenlock Beds merely receive a passing mention in Murchison's 'Silurian System' (1839) p. 315, and also in his 'Siluria' 5th ed. (1872) p. 59. In the last-named work, however, sections are drawn across the Builth country, and the Wenlock Beds are grouped together as a series of mudstones containing graptolites and *Orthoceras*. A summary account of the Silurian rocks of the Builth district is found in Mem. Geol. Surv. vol. i (1846) p. 22, and the chief localities for fossils are recorded in vol. ii, pt. i (1848) p. 327, etc. The only suggestion of their possible division into zones is given by Lapworth in his 'Geological Distribution of the Rhabdophora.'[1] He separates the zone of *Cyrtograptus Murchisoni* from higher beds in which *C. Linnarssoni* is a characteristic fossil. At the end of the same paper he also states his opinion that the day will come when 'by the aid of the lowly graptolite the geologist of the future will be able to read off the natural succession' in the monotonous Silurian mudstones of Britain with ease and certainty.

The Long Mountain.

Prof. Watts has written two papers dealing with the Silurian rocks of the Long Mountain. In the first of these, 'On the Igneous & Associated Rocks of the Breidden Hills in East Montgomeryshire & West Shropshire,'[2] he divides the Wenlock Shales of the area into an upper and lower series. In a paper read before the British Association in 1890 and subsequently published in abstract,[3] he modifies his earlier views and considers that the beds represent the upper part of the Wenlock Shale together with the Wenlock Limestone. My own work confirms his later opinion.

The Dee Valley.

The Llangollen Basin has been studied by many geologists. The most important recent paper is one by Mr. Lake on 'The Denbighshire Series of South Denbighshire.'[4] This paper contains a summary of the earlier work on the beds exposed in the area, and the author divides the Wenlock Beds of the district as follows:—

Moel Ferna Slates, with *M. Flemingii* and *M. priodon*.
Pen-y-glog Grit.
Pen-y-glog Slates, with *M. personatus*, *M. priodon*, etc.

[1] Ann. & Mag. Nat. Hist. ser. 5, vol. vi (1880) p. 201.
[2] Quart. Journ. Geol. Soc. vol. xli (1885) p. 532.
[3] Rep. Brit. Assoc. 1890 (Leeds) p. 817.
[4] Quart. Journ. Geol. Soc. vol. li (1895) p. 9.

My work supplies some further details, and confirms his view that in part the Moel Ferna Slates are approximately on the same horizon as the beds with *Cyrtograptus Linnarssoni* in the Long Mountain.

III. The Builth District.

That part of the Builth district which is occupied by Wenlock Shales, and which I have mapped in detail, includes a roughly triangular area extending from Disserth on the north to Llanafan-fechan on the west and Aberedw Hill on the east. (See Map, fig. 4, p. 385.)

The conspicuous features in the landscape are due to the igneous rocks associated with the Llandeilos, and the Ludlows also attain a considerable height south-west, south, and south-east of the town, forming Mynydd Aberedw and Mynydd Epynt.

The Wenlock Shales only give rise to gentle undulations sloping down to the banks of the Wye and its tributaries, the higher ground being generally occupied by the harder and more flaggy beds of the series. Exposures are less common than in the older beds, and close to the town all are concealed beneath a tract of alluvium.

The general structure of the rocks in the Builth district seems to have resulted from the superposition of two sets of subsequent earth-movements: these have affected a series of flags and shales, the upper members of which overlap the lower.

The first set of movements impressed upon the beds formed part of a series of folds whose axes ran north-east and south-west. This set of movements was responsible for the production of the syncline which occupies the northern and north-western parts of the district. The second set of movements belongs to a later period, and the folds have their axes running in a general east-and-west direction.

It seems probable that one of the anticlinal axes of this later set of movements must have run approximately through Newbridge, judging by the general effect of this folding on the whole area of the Borderland. This would result in the raising of the district on the north and north-west of Builth, to a higher level than the district on the east. Hence this effect, combined with the effect of the previous set of movements and subsequent denudation, has caused beds to be exposed in the north and north-west of the area, which are hidden by overlap to the east. The overlapping is clearly indicated on the west of the town, but is only partial there, while it is complete (as regards the Wenlock Shales) on the east.

The beds exposed in this area range from Llandeilo to Ludlow, but the Bala and Lower Llandovery rocks do not seem to be present. Hence there is a marked unconformity between the Upper Llandovery and Llandeilo Groups.

Detailed Description of the Beds.

(i) *The Llandovery Beds.*

Between the Llandeilos and the Wenlock Shales in the northern part of the Builth district runs an almost continuous band of Llandovery Grit, which demands brief notice. It is easily recognizable, and has yielded *Pentamerus oblongus*, Sow., *P. undatus*, Sow., and *Stricklandinia lens*, Sow. It seems, therefore, to represent the upper part of the Llandovery Series, and rests unconformably upon the Llandeilo rocks. It is well exposed at Trecoed, and in the quarry at the end of Pencerrig Lake; south-west of Pencerrig it is overlapped by the Wenlock Shales, except where it crops out on the banks of the Wye.

In every case this *Pentamerus*-grit is succeeded by a narrow band of soft, black, thinly-bedded shales, which differ in these characters from the succeeding Wenlock Shales. Unfortunately these black beds seem to be unfossiliferous, but I would suggest that they possibly represent the Tarannon Shales, although in the absence of entirely satisfactory evidence nothing more definite can be said.

The grits and shales dip beneath the Wenlock Group at an angle of 25° at Trecoed, but the angle is as much as 40° in the bed of the Wye.

(ii) *The Wenlock Shales.*

(*a*) Section north-west of Builth.

With regard to the area which lies north and north-west of Builth, it seems best to consider all the sections together; for, though exposures are fairly common, there are so few continuous sections that, unless the area is considered as a whole, no connected idea of the sequence can be obtained.

(1) Zone of *Cyrtograptus Murchisoni*, Carr.—Beds characterized by the predominance of *C. Murchisoni* form the lowest part of the Wenlock Shale Series in the district. Unfortunately the lowest beds of this zone are but rarely seen, since they are overlapped by the higher, which in places also conceal even the Llandovery Grit, and rest with a still greater unconformity upon the Llandeilo rocks. They are exposed, however, at the bottom of the gully occupied by the stream which flows out of Pencerrig Lake, and are seen to consist of soft, pale, calcareous shales alternating with harder beds of calcareous flags. The higher beds consist almost exclusively of these hard flagstones.

The beds dip N. 30° W., at 30°. They are very fossiliferous; slabs completely covered with *C. Murchisoni* are common, and other forms also are abundant. A list of the graptolites found at this locality is given in Table I, col. A (p. 378).

In addition to the graptolites *Acidaspis Prevosti*, Barr. = (*Hughesi*, Salt. ?), *Orthoceras subundulatum*, Portl., *O. primævum*, Forbes,

Cardiola interrupta, Brod., *Chonetes minima*, Sow., and several other small brachiopoda occur.[1]

The higher beds of this zone, which, as I have said, are more flaggy than those just mentioned, are well exposed at Trecoed beside the track leading from the high road to the Farm, in the old quarry north of Llanelwedd Hall, and in the bed of the Wye.

At Trecoed the *C.-Murchisoni* zone has yielded the graptolites enumerated in Table I, col. B (p. 378). Specimens of *Acidaspis Prevosti* (=*Hughesi?*), *Cardiola interrupta*, and other small brachiopoda are also abundant.

In the old quarry north of Llanelwedd Hall the beds dip at 35°, S. 30° E.; they overlap on to the Llandeilo rocks and yield the graptolite-fauna recorded in Table I, col. C. Other fossils found here include *Acidaspis Prevosti*, *Orthoceras* sp., *Glassina læviuscula* (Sow.), *Atrypina Barrandei*, Dav.?, *A. reticularis*, Linn. (young), and *Lingula Symondsi*, Salt.?

The fauna at these two localities is very similar to that which occurs at Pencerrig, but *C. Murchisoni* is not so abundant, and *Retiolites Geinitzianus* is absent. Specimens of *Monograptus riccartonensis* are occasionally met with in the highest horizons at these localities, indicating the coming in of the fossil which attains its maximum development in the succeeding beds. The beds of the *C.-Murchisoni* zone which contain *M. riccartonensis* must be regarded as the highest belonging to that zone, and at Trecoed they are succeeded, within a very short distance, by beds in which *M. riccartonensis* is almost the only fossil found.

In the bed of the Wye I was able to obtain only *Cyrtograptus Murchisoni* and *Monograptus vomerinus* (Nich.) var. *α*.

(2) Zone of *Monograptus riccartonensis*, Lapw.—The beds which succeed those containing *Cyrtograptus Murchisoni* as the predominant form are characterized by the abundance of *M. riccartonensis.* This graptolite often occurs to the exclusion of almost every other form, though it is not so abundant in the Builth district as in some other areas. These beds do not differ in any important lithological character from the highest horizons of the underlying zone, but the fauna is sufficiently distinct to mark them off.

The beds are exposed for a thickness of about 12 feet in the lower part of an old quarry behind Castle Crab Farm. They consist of hard, grey, calcareous flagstones, often breaking with a splintery fracture. The fossils are seen to occur in bands, though there appears to be little or no difference in the lithological character of these bands, and there is no difference in the fauna that they contain. The fauna found here includes that enumerated in Table I, col. F[1] (p. 378). *Orthoceras* sp. is also abundant.

The coming in of *Monograptus dubius*, Suess, is characteristic of

[1] I have to express my best thanks to Mr. F. R. C. Reed for kindly naming the brachiopoda mentioned in this paper.

this horizon, though it has not yet become a common form. The zone is also exposed for some little distance along the strike of the beds behind Grove Cottages, on the Rhayader road; the beds are striking N. 40° E., and yield the forms recorded in Table I, col. E (p. 378).

The only other exposure of the *M.-riccartonensis* zone is to be found on the banks of the Wye. This section is interesting, because it affords a means of detecting the alteration in the strike of the beds as they sweep round the exposure of Llandeilo rocks. At first the beds strike N. 30° E., then they bend gradually away, till a little way below the railway-bridge the strike is N. 60° E., and a short distance above the bridge the beds run very nearly due north and south. Here the beds are very poor in fossils. *Monograptus capillaceus*, Tullb., and *M. dubius* were the only graptolites found. *M. capillaceus* seems to be entirely confined to this zone of *M. riccartonensis*: it often occurs in abundance, associated with the zone-graptolite, and it may be taken to indicate the zone even where the typical fossil itself is not very common.

It is unfortunate that the best exposure of the *M.-riccartonensis* zone is a little outside the area with which I am dealing. It occurs on the other side of the fold, where exposures are by no means numerous, and is to be found on the banks of the Ithon, where that stream makes a big bend north-east of Newbridge; at this locality *M. riccartonensis* and *M. capillaceus* are very abundant. The *M.-riccartonensis* zone probably attains a maximum thickness of about 300 feet.

(3) Zone of *Cyrtograptus symmetricus*, sp. nov.—In the south-western parts of the district a considerable thickness of flagstones succeeds the *M.-riccartonensis* zone. These beds are exposed above the railway-bridge on the Wye, in the railway-cutting near Builth Road Station and south-east of the Wye, in a small quarry east of the station, and in the road leading to it. These beds, however, which are of the nature of coarse sandy flags, seem to die out north-eastward. They are certainly not present at Castle Crab, where the highest beds of the *M.-riccartonensis* zone are followed in an apparently normal succession by beds in which *C. symmetricus* is the characteristic form.

The beds belonging to this zone consist of alternations of hard flagstones with very soft fissile shales, which have a tendency to weather deeply. The zone is best exposed in a small quarry, in a field south-east of Castle Crab, which has been excavated across the strike. The strike here runs N. 30° E., and the beds dip at 30°, N. 30° W. They consist almost entirely of the softer shales, and are very fossiliferous; they have yielded the graptolites enumerated in Table I, col. F^2 (p. 378). *Orbiculoidea*, *Chonetes minima*, *Cardiola interrupta*, and *Orthoceras* sp. are also found.

Beds with a similar fauna were discovered up an old cart-track, which leaves the road just where it bends towards Castle Crab, behind Castle Crab, at the top of the quarry mentioned above, and in

the lowest beds exposed in the quarry at Coed Mawr (see Table I, col. G[1], p. 378). This quarry has been worked across the strike of the beds, and the rocks are seen to be dipping at 25°, parallel to the direction of the main road; the beds with *Cyrtograptus symmetricus* form the floor of the quarry, and are seen on the dip-face.

A noteworthy feature in the fauna is the abundance of *Monograptus dubius*, Suess, while *M. priodon* (Bronn), so common in the earlier horizons, is rare. In the north-eastern part of the district the zone is not more than 50 feet thick, but where the flagstones are developed it attains a thickness of fully 200 feet.

(4) Zone of *Cyrtograptus Linnarssoni*, Lapw.—The soft shales which form the base of the quarry at Coed Mawr, and are crowded with *C. symmetricus*, are succeeded by a series of hard calcareous flagstones with limestone-concretions, which are exposed in vertical section for a thickness of 20 feet. Fossils may be found throughout this thickness of rock by diligent searching, but are most abundant in a band 3 feet above the *C.-symmetricus* zone, and again 10 feet higher up; the same graptolites are found in these two bands, but this fauna is quite distinct from that of the softer shales forming the floor of the quarry. The hard flagstones are deeply weathered at the summit of the quarry; they contain the graptolites enumerated in Table I, col. G[2] (p. 378). These beds represent, then, the base of the *C.-Linnarssoni* zone.

The only other exposure of this zone is the excellent section seen on the Rhayader road, north-east of Builth Road Station. The road cuts the beds obliquely across their strike; the beds at the extreme southern limit should probably be included in the *C.-symmetricus* zone, since they have yielded that zone-fossil, but these are at once succeeded by higher beds, with a fauna in all respects similar to that found in Coed Mawr Quarry. The beds consist of hard calcareous shales, with large limestone-concretions; they have yielded the forms enumerated in Table I, col. H (p. 378). *Orthoceras subundulatum*, *O. primævum*, *O. striato-punctatum* var. *originale*, Barr., and *Cardiola interrupta* are also abundant. The rarity of *Monograptus priodon* and the incoming of *M. Flemingii* characterize this horizon. The *C.-Linnarssoni* zone appears to be about 200 feet thick.

It is succeeded by a considerable thickness of coarse unfossiliferous flagstones; these are exposed at the end of the Rhayader road-section in an old quarry; for some little distance along a new road leading to Pencerrig; and in a field north of Castle Crab. They are also exposed on the south-west, along the road to Llanafan-fawr, just above where it crosses the railway-line, and in the railway-cutting itself. This band of flagstones is of great interest, for as it bends round south-eastward it overlaps the lower members of the series, so that eventually only a small part of the *Monograptus-riccartonensis* zone and the *Cyrtograptus-Murchisoni* zone come out below it.

GRAPTOLITE-FAUNA OF THE BUILTH DISTRICT.

TABLE I. Names of Species and Varieties. [C=very common; c=common; r=somewhat rare; R=very rare.]	Zone of *C. Murchisoni.*				Zone of *M. riccartonensis.*			Zone of *C. symmetricus.*		Zone of *C. Linnarssoni.*		Zone of *C. rigidus.*		Zone of *C. Lundgreni.*		
	A	B	C	D¹	D²	E	F¹	F²	G¹	G²	H	I	K	L	M	N
	Pencerrig.	Trecoed.	Llanelwedd.	River Wye.	River Wye.	Grove Cottages.	Castle Crab.	Castle Crab.	Coed Mawr.	Coed Mawr.	Builth Road.	Dulas Brook.	Nant Prophwyd.	Neuadd.	Gaufron Uchaf.	AberedwHill.
Monograptus priodon (Bronn)	C	C	C	...	...	c	c	r	...	...	R					
Retiolites Geinitzianus, Barr.	C															
Cyrtograptus Murchisoni, Carr.	C	C	C	C												
,, ,, var. *crassiusculus*, Tullb.	r															
Monograptus vomerinus (Nich.) var. *α*	C	C	C	c	...	C	...	c	...	...	c	c	c			
,, ,, var. *β*	C	...	...	...	...	...	...	c								
Stomatograptus, sp.	r															
Monograptus basilicus, Lapw.	c	...	...	...	...	C	...	...	...	...	c	c	...	...	...	C
M. Hisingeri, Carr., var.	c	...	...	...	...	c	...	c	...	...	...	...	...	...	...	C
M. riccartonensis, Lapw.	...	R	R	...	...	c	C									
M. capillaceus, Tullb.	...	...	...	...	C	C										
M. dubius, Suess	...	...	...	...	r	r	r	c	c	C	C	C	C	C	C	C
Cyrtograptus symmetricus, sp. nov.	...	...	...	...	...	...	...	C	C							
C. Linnarssoni, Lapw.	...	...	...	...	...	...	...	...	...	C	C					
Monograptus Jækeli, Perner	...	...	...	...	...	...	...	...	...	...	r					
Cyrtograptus rigidus, Tullb.	...	...	...	...	...	...	...	...	...	...	...	C				
Monograptus retroflexus, Tullb.	...	...	...	...	...	...	...	...	...	...	...	r	C			
M. Flemingii (Salt.) var. *α*	...	...	...	...	...	...	...	...	...	c	c	C	C			
,, ,, var. *β*	...	...	...	...	...	...	...	...	...	...	...	c	c	...	...	r
,, ,, var. *γ*	...	...	...	...	...	...	...	...	...	...	...	...	...	C	c	C
,, ,, var. *δ*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	c	C
Cyrtograptus Lundgreni, Tullb.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	r	C
Monograptus colonus-type	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	R

[NOTE.—In this and the succeeding Tables, the fossils are named in the order of their appearance, as far as may be.]

The alteration in the strike of the beds is well seen in the sections along the Rhayader road, in the Wye, and on the Llanafan-fawr road. At the first of these localities the strike is N. 40° E.; in the river the beds appear to be striking due north and south, while on the Llanafan-fawr road their trend is N. 15° W.

(5) Zone of *Cyrtograptus rigidus*, Tullb.—The fossiliferous beds which succeed the flagstones are exposed in three places only in this part of the district; in Dulas Brook, just where it is crossed by the Llandrindod road, in a quarry near Nant Prophwyd, north-west of Cwm-bach, and on the banks of Nant Prophwyd, below the quarry.

The exposure in Dulas Brook is small, but very fossiliferous. The beds are striking in the same general direction as the stream; they consist of hard calcareous shales, yielding the graptolite-fauna of Table I, col. I (p. 378).

The quarry near Nant Prophwyd contains beds of precisely similar lithological character, but they are probably somewhat higher in the series, though still belonging to the same zone. The beds strike across Nant Prophwyd at right angles, and the forms enumerated in Table I, col. K, are characteristic. *Omphyma*, *Orthoceras primævum*, and *O. subundulatum* also occur.

Monograptus retroflexus, Tullb., seems to be confined to this zone; it is quite as characteristic a fossil as the zone-fossil, and in certain localities would seem to be even more abundant. Observation shows that it is commoner in the highest parts of the zone, though usually present throughout; forms of *M. Flemingii* (Salt.) begin to occur very abundantly at this horizon.

I have not been able to estimate the thickness of the *C.-rigidus* zone, as I have not seen the fossiliferous beds anywhere resting directly upon the flags; nevertheless, I consider that the beds exposed in Dulas Brook are very near the base, since the flagstones seem to occupy the hill south of the stream. I cannot state where the upper limit should be placed; but, judging from other localities, I think that the beds in the quarry near Nant Prophwyd cannot be very far down in the zone.

(6) Zone of *Cyrtograptus Lundgreni*, Tullb.—The lower beds of the succeeding zone are not very fossiliferous in this part of the area; they are exposed in an old quarry off the Llandrindod road, north-east of Neuadd, and for some little distance along the bank on the east side of the road. The beds consist of alternations of shales and more flaggy beds; they have yielded a few graptolites (see Table I, col. L, p. 378). A pygidium of *Phacops* was also found.

A good exposure of the calcareous shales is seen behind Gaufron Uchaf Farm, and as a drain had recently been made I found an opportunity of examining a considerable quantity of most promising material, but, unfortunately, could discern no trace of a graptolite or any other organism. Higher shale-beds are exposed in a copse west

of Gaufron Uchaf, and along a cart-track south of the copse, these were more fossiliferous, and yielded the graptolites enumerated in Table I, col. M (p. 378).

These calcareous shales are again exposed in the lane leading down to Wern Fawr, and at the bottom of it are seen to be succeeded by hard flagstones. The flagstones are well exposed in the quarry south-west of Neuadd, where certain bands are richly fossiliferous, and have yielded fragments of trilobites and many brachiopods, but no determinable graptolites. The beds strike N. 30° E., and occupy the greater part of the railway-cutting to the north between Neuadd and Gaufron Isaf.

Beds, which evidently succeed this flagstone-band, are exposed in an old quarry south-west of Gaufron Isaf; they are somewhat peculiar, since they consist of a series of calcareous-micaceous flagstones and sandstones, with bands of rotten limestone. The beds have yielded *Monograptus colonus*, Barr. ?, *M. Nilssoni*, Barr., and *Dayia navicula*, Sow. ?, and must therefore be regarded as belonging to the Lower Ludlow Series: consequently, all the beds which lie above them must also be of Ludlow age.

The highest beds seen are hard, siliceous, and light in colour; they are exposed in a quarry beyond Wern Fawr, and are seen to dip 60° north-westward. Precisely similar beds are also exposed in a quarry south-east of Bryn Wood, where the dip is still steeper; and again in a quarry beyond Pen-y-rhiw, where the dip is still very steep, but in a south-easterly direction. Consequently, the central axis of the fold must be very near that locality.

The succession in the north and north-west of the Builth district may be summarized as follows (in descending order):—

		Feet.
LUDLOW	Hard, light-grey, siliceous flags.	
	Micaceous sandy shales with rotten limestone-bands.	
WENLOCK SHALES.	Calcareous flagstones with fossiliferous bands.	
	(6) Calcareous fissile shales with beds of flagstone. =Zone of *Cyrtograptus Lundgreni*.	
	(5) Hard, grey, calcareous shales with graptolites. =Zone of *Cyrtograptus rigidus*.	
	Light-coloured flags, unfossiliferous	400
	(4) Grey calcareous flags and shales, with limestone-concretions	300
	=Zone of *Cyrtograptus Linnarssoni*.	
	(3) Soft shales with harder flaggy beds	200
	=Zone of *Cyrtograptus symmetricus*.	
	(2) Hard calcareous flagstones	300
	=Zone of *Monograptus riccartonensis*.	
	(1) Soft fissile shales alternating with flags. =Zone of *Cyrtograptus Murchisoni*.	

(b) Section along the River Irfon.

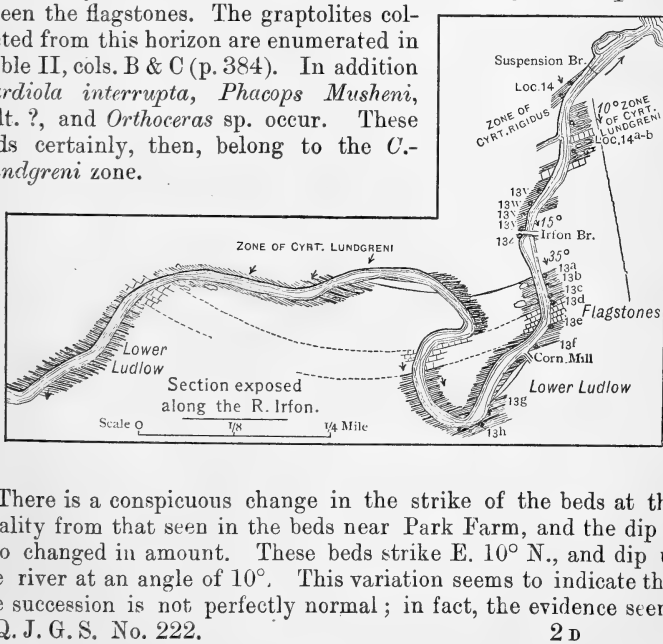
A little to the west of the town of Builth a magnificent section is exposed in the River Irfon, and in the summer of 1898 exceptional facilities were afforded for working it, owing to the prolonged drought and the low state of the water.

There is an almost continuous section exposed on one bank or the other, from immediately above the suspension-bridge to beyond Wern Wood; but the exposures in the upper parts of the course of the river are merely repetitions of beds seen lower down, and therefore the most important part is that seen between the suspension-bridge and the high cliff just beyond the weir. This affords a section from beds of undoubted Wenlock-Shale age into a set of beds whose fauna proclaims them to belong to the Lower Ludlow.

There are no rock-exposures between the mouth of the Irfon and the suspension-bridge; but between that bridge and Park Farm several rock-exposures were visible in the summer of 1898, though they must, as a general rule, be covered by the water: these are all on the left bank. The beds strike N. 30° E., and dip in towards the river at an angle of 25°; they consist of a series of hard calcareous shales, overlain by a softer shale-series. Fossils are abundant, and include those enumerated in Table II, col. A (p. 384). These beds undoubtedly represent the zone of *Cyrtograptus rigidus*.

The next beds in ascending order are seen on the right bank of the river; they are exposed from a point opposite where the road curves away from the farm on the left bank till where the convex curve of the right bank begins. These beds consist for the most part of hard calcareous flags with large limestone-concretions, some of which measure as much as 3½ feet in transverse diameter. Graptolites are fairly abundant in the more shaly bands, which are seen between the flagstones. The graptolites collected from this horizon are enumerated in Table II, cols. B & C (p. 384). In addition *Cardiola interrupta*, *Phacops Musheni*, Salt. ?, and *Orthoceras* sp. occur. These beds certainly, then, belong to the *C.-Lundgreni* zone.

Fig. 1.—*Map.*



There is a conspicuous change in the strike of the beds at this locality from that seen in the beds near Park Farm, and the dip is also changed in amount. These beds strike E. 10° N., and dip up the river at an angle of 10°. This variation seems to indicate that the succession is not perfectly normal; in fact, the evidence seems

Fig. 2.—*Section from Trecoed to Wern Fawr, north-western portion of the Builth District.*
(Scale: $4\frac{1}{2}$ inches = 1 mile.)

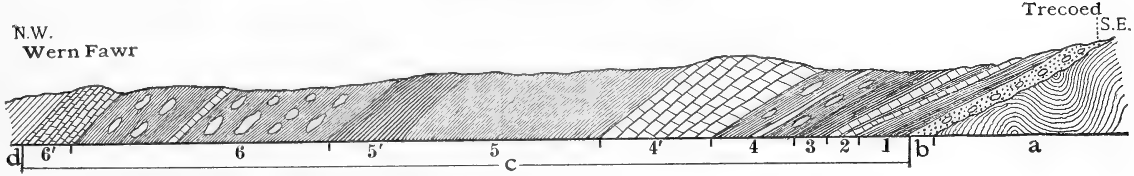
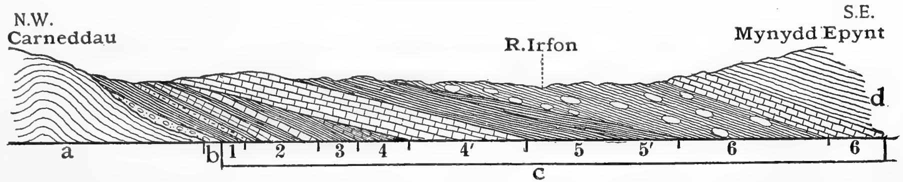


Fig. 3.—*Section from Mynydd Epynt to Carneddau, western portion of the Builth District.*
(Scale: $4\frac{1}{2}$ inches = 1 mile.)



a = L'andeilo Beds.
b = Llandovery Beds.
d = Ludlow Beds.

c = Wenlock Shales.
- 1 = Zone of *Cyrtograptus Murchisoni.*
- 2 = Zone of *Monograptus riccartonensis.*
- 3 = Zone of *Cyrtograptus symmetricus.*
- 4 = Zone of *Cyrtograptus Linnarssoni.*
- 4′ = Flagstones.
- 5 = Zone of *Cyrtograptus rigidus* (lower portion)
- 5′ = do. do. (upper portion).
- 6 = Zone of *Cyrtograptus Lundgreni.*
- 6′ = Flagstones.

to me to show that there has been some overlap on the part of the beds belonging to the zone of *Cyrtograptus Lundgreni*, and that this overlap conceals the highest beds of the *C.-rigidus* zone. This view is certainly borne out by the palæontological evidence, for the fauna of the beds near Park Farm suggests the beds of Dulas Brook rather than those of Nant Prophwyd.

In the normal state of the river these lowest beds of the *C.-Lundgreni* zone must be only exposed in vertical section along the bank; this section reaches a maximum height of 5 feet just below the point at which a small stream comes in on the opposite bank.

The section is continued again on the left bank, the lowest beds observed being the same as those last seen on the right bank, and consisting of hard calcareous flagstones. These beds are succeeded by a series of soft black shales, which are exposed in vertical section in the bank, and are fully 4 feet thick. They are deeply stained with iron, and much weathered; the underlying flags are exposed for a considerable distance at the water-level, and the softer beds pass beneath the water near an old oak-tree, about 50 yards below Irfon Bridge. The graptolites of these soft beds are enumerated in Table II, cols. D & E (p. 384).

The next good exposure is about 20 yards below the bridge. Here the beds consist of hard calcareous shales and flagstones with limestone-concretions; the strike is the same as before, but the dip has increased to 15°. Graptolites, as before, are abundant in the softer bands, and some of the specimens of *Monograptus irfonensis*, sp. nov., reach a length of $8\frac{1}{2}$ inches. This fossil is particularly abundant in a band about 15 inches thick, which is marked on the map (fig. 1, p. 381) as $13x$; other fossils found here are enumerated in Table II, col. F (p. 384) This band is succeeded by 12 feet of hard flags, which are overlain by another graptolite-bearing band, in which *M. Flemingii* var. γ is the predominant form. This is succeeded by another series of flags, and then immediately below the bridge by still another fossiliferous band, the fossils of which are enumerated in Table II, col. H. This band is followed by another series of flagstones, and the exposure comes to an end.

There is then a considerable gap in the section, there being no exposures on either bank for some little distance above the bridge. Below the big bend of the river excellent exposures, however, are seen on both banks, and the beds form a high cliff-section on the right bank. They consist of hard calcareous shales with large limestone-concretions; the strike is still E. 10° N., but the dip has yet further increased, and is now 35°.

These beds have yielded only two graptolites (see Table II, col. I, p. 384): *Monograptus Flemingii* var. δ and *M. dubius*, *Orthoceras striato-punctatum* var. *originale*, *O. subundulatum*, and *Cardiola* sp. are also abundant. They are succeeded by a well-marked band of flagstones, in which, after much searching, I discovered two specimens of *M. dubius* and a head-shield and pygidium of *Phacops Musheni.*

2 D 2

Above this belt of flagstones come a series of dark shales without concretions, in which fossils are very abundant. These include forms of *Monograptus colonus*, *M. bohemicus* (Barr.), *M. Nilssoni* (Barr.), etc., and therefore the beds must be regarded as belonging undoubtedly to the Lower Ludlow.

Exposures are numerous in the upper parts of the river, but consist merely of repetitions of the beds just described. They need not, therefore, be dealt with in detail, since they present no new features. Sections confirming the upper part of the Irfon section are also to be seen in the road leading past the Cottage Hospital, and again in that leading past the Vicarage; in both these the beds yield a typical Lower Ludlow fauna, and hence the Ludlow rocks should be represented on the map very much nearer to the town of Builth than they are at present.

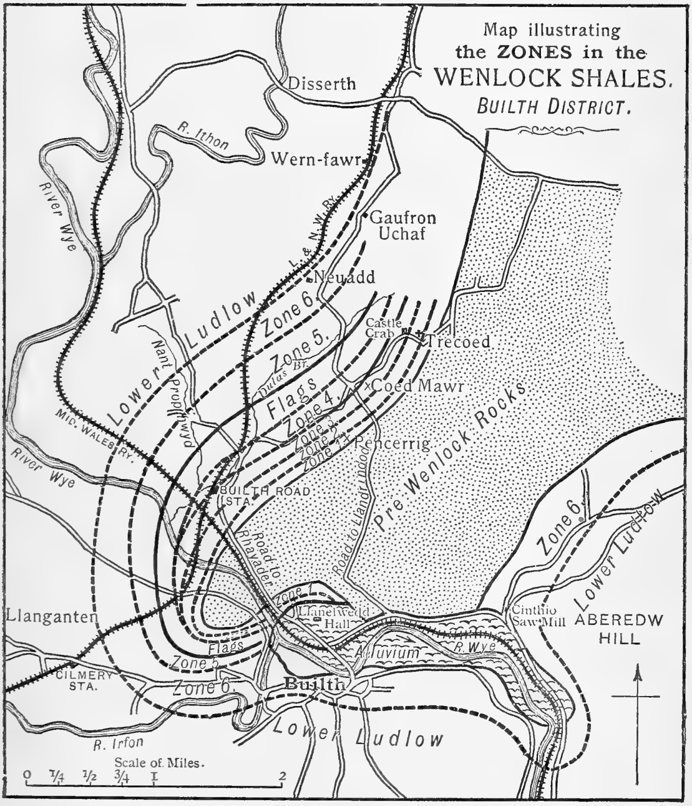
Table II. Names of Species and Varieties. [C=very common; c=common; r=somewhat rare; R=very rare.]	RIVER IRFON GRAPTOLITES.								
	Zone of *Cyrtograptus rigidus.*	Zone of *Cyrtograptus Lundgreni.*							
	A	B	C	D	E	F	G	H	I
Locality Nos. (See Map, fig. 1, p. 381.)	14	14 *a*	14 *b*	13 *v*	13 *w*	13 *x*	13 *y*	13 *z*	13 *a–d*
Monograptus vomerinus (Nich.) var. *a*	C	C	C	C	C	C	C	C	
M. basilicus, Lapw.	C	...	...	...	...	C	...	C	
M. dubius, Suess	C	C	C	C	C	C	C	C	C
Cyrtograptus rigidus, Tullb.	C	...	...	R					
Monograptus Flemingii (Salt.) var. *a*	c								
" " var. *β*	r								
" " var. *γ*	...	...	C	C	C	C	C	C	
" " var. *δ*	...	...	...	...	...	...	...	C	C
Cyrtograptus Lundgreni, Tullb.	...	C	C	...	...	...	...	C	
Monograptus irfonensis, sp. nov.	...	...	...	...	...	...	...	C	

(*c*) Aberedw Hill.

East of Builth the only zone exposed is that of *Cyrtograptus Lundgreni*. The beds belonging to this horizon are seen on the Presteign road just above Cinthio Sawmill (see map, fig. 4, p. 385), on the road that leads past the sawmill, just after it has crossed Cinthio Brook, and in the brook itself for a short distance. The beds consist of hard calcareous shales and flagstones with limestone-concretions, and are exposed near the sawmill for a thickness of 12 feet. They dip 15° in a direction E. 30° S., and have yielded the fauna enumerated in Table I, col. N (p. 378).

The lowest beds of the Ludlow Group are seen in a quarry west of Pen-y-cloddiau, and in the stream that runs past that farm. Between these beds, or perhaps representing them in part, occurs a discontinuous bed of limestone, which I believe to be the representative of the Wenlock Limestone in this district. This limestone is exposed in an old quarry north-east of Pen-y-cloddiau, and again on the Aberedw road near Llanfaredd.

Fig. 4.



The beds yield an abundant fauna of trilobites and brachiopods. The following have been recognized:—*Phacops Musheni*, Salt., *Leptæna rhomboidalis*, Wilck., *Wilsonia Wilsoni*, Sow., *Atrypa marginalis*, Dalm., *Pentamerus* sp., *Orthis rustica*, Sow., *O. hybrida*, Sow., corals, and crinoid-stems.

The Irfon section and that on Aberedw Hill are extremely useful, as confirming the succession of the upper series, which might have remained doubtful had no other exposures than those in the

northern part of the district been examined. As it is, the succession is confirmed, and there can be no doubt, I think, that the Wenlock Shales of the Builth district are capable of being divided into the following six distinct zones (in descending order):—

	Feet.
(6) Zone of *Cyrtograptus Lundgreni*, Tullb.	about 440
(5) Zone of *Cyrtograptus rigidus*, Tullb.	about 400
(4) Zone of *Cyrtograptus Linnarssoni*, Lapw.	150
(3) Zone of *Cyrtograptus symmetricus*, sp. nov.	150
(2) Zone of *Monograptus riccartonensis*, Lapw.	300
(1) Zone of *Cyrtograptus Murchisoni*, Carr.	200

General Sequence of Events in the Builth District.

The general sequence of events in the Builth district is now seen, therefore, to have been as follows:—

(1) Subsidence of the old Llandeilo ridge, inducing deposition on a sinking shore-line, and consequently overlap of higher beds on to lower.

(2) Production of a series of folds whose axes ran north-east and south-west. This set of movements was responsible for the synclinal fold which occupies the northern part of the area. These movements were probably of post-Silurian age, since they affected the rocks up to the Ludlows, but not apparently the Old Red Sandstone.

(3) Production of a second set of earth-movements resulting in a series of folds whose axes ran in a general east-and-west direction. These movements were probably post-Carboniferous, though the evidence of age is not seen in this district.

(4) Denudation of the rocks thus folded.

IV. The Long Mountain District.

The general structure of the Long Mountain is very simple. The beds are bent into a syncline whose axis runs north-east and south-west, and the rock-succession presents many features in common with the Builth district just described. Here again there must have been deposition in a sinking area of older rocks, resulting as before in overlap; here also, as in the Builth area, the older rocks are exposed on the outer edges of the trough. Denudation has, however, laid bare lower beds of the Wenlock Shales south of the Long Mountain than any that are exposed on the north side of the trough: these are to be seen near Chirbury.

The outcrop of Ludlow rocks as indicated upon the Geological Survey map is too limited, and seems to include only the Upper Ludlow. Beds of Lower Ludlow age extend down the mountain-slopes on all sides, while the true Wenlock Shales are in reality restricted to a mere fringe, occupying the lowest ground of the area (see Map, fig. 9, p. 395).

The succession is very similar to that at Builth. The oldest rocks seen on the north side of the district are a series of shales

with associated igneous rocks, which Prof. Lapworth and Prof. Watts refer to the lower part of the Bala Series.[1] These are unconformably overlain by Llandovery Beds, which are in turn succeeded unconformably by the Wenlock Shales.

In the south, the Llandovery Beds rest on different members of the Ordovician rocks. Near Betton they rest immediately upon the Llandeilos (Middleton Group), but farther west the unconformity is less clearly defined. The succession between the Llandovery and Wenlock Beds appears quite conformable, though much is concealed by alluvial deposits.

Throughout the whole of the Long Mountain area the Wenlock Shales pass up gradually into the Ludlow, and these in their turn into the highest rocks seen, namely, the Old Red Sandstone, which is exposed near the summit of the Long Mountain.

Detailed Description of the Beds.

Before describing in detail the sections in the Wenlock Shales exposed at various points on the flanks of the Long Mountain, it is necessary to say a little about the beds which underlie them in this area.

(i) *Llandovery-Tarannon (?) Beds.*

Prof. Watts has already shown that beds of Upper Llandovery age are exposed on the flanks of Middletown Hill near Buttington Railway-station. They are also present in the southern part of the district, near Betton, and in Hailsford Brook. Apart from the palæontological evidence, the unconformity of these beds to the older rocks is hard to detect in the north, but it is very marked at some localities in the south, and can be very clearly seen along a cart-track near Betton, which leads up to an old quarry excavated in the Llandeilo rocks (Middleton Group).

In all these localities the Llandovery commences with a well-marked grit-band, which is invariably succeeded by a belt of fine shales, purple in the north, though with paler bands in the southern part of the district. These shales are unfossiliferous, but Prof. Watts suggests that they should be referred to the Tarannon Shales, and with this view I am in agreement. They are unlike any Wenlock beds known to me, and north-east of Betton, near The Stubbs, they are succeeded by strata which very closely resemble the base of the Wenlocks, though I was not successful in finding fossils in them, and therefore am unable to say definitely that they are of Wenlock age.

(ii) *The Wenlock Shales.*

In describing the Wenlock Shales of the Long Mountain area, I propose to deal with continuous sections exposed along streams or roads, and for this purpose shall group my sections under three heads:—

(A) Sections on the North Side;
(B) Sections on the West Side;
(C) Sections on the South Side.

[1] Proc. Geol. Assoc. vol. xiv (1894) p. 320.

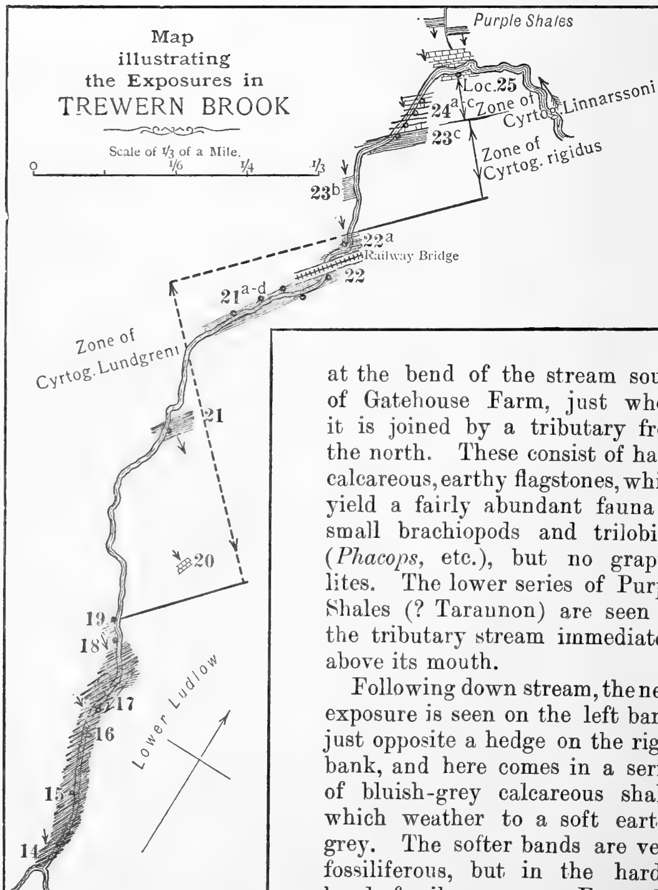
(A) Sections on the North Side.

(Aa) Trewern Brook.

An excellent section, comprising all the beds of Wenlock Shale seen on the north side of the Long Mountain, is laid bare on the banks of Trewern Brook and its tributaries north-east and south of Middletown Station.

Zone of *Cyrtograptus Linnarssoni*, Lapw.—The lowest beds of the Wenlock Shale Series are exposed on the left bank

Fig. 5.



at the bend of the stream south of Gatehouse Farm, just where it is joined by a tributary from the north. These consist of hard, calcareous, earthy flagstones, which yield a fairly abundant fauna of small brachiopods and trilobites (*Phacops*, etc.), but no graptolites. The lower series of Purple Shales (? Tarannon) are seen in the tributary stream immediately above its mouth.

Following down stream, the next exposure is seen on the left bank, just opposite a hedge on the right bank, and here comes in a series of bluish-grey calcareous shales which weather to a soft earthy grey. The softer bands are very fossiliferous, but in the harder bands fossils are rare. From this locality I collected the forms enumerated in Table III, col. A (p. 390). The beds here dip S. 10° E., at 40°.

Identical beds are also exposed behind Coppice House, and in the road between the railway-station and Southbank they exhibit exactly the same lithological characters: namely, a series of alternating calcareous shales and flags underlain by hard flagstones. The dip is the same in amount, but the direction has slightly changed to S. 20° E. The beds here yielded *Cyrtograptus Linnarssoni*, *Cyrtograptus* sp., *Monograptus Flemingii* var. *a*, *M. Jækeli*, Perner, *M. priodon*, *M. vomerinus*, *M. dubius*, and *Orthoceras subundulatum*. These beds undoubtedly represent the *C.-Linnarssoni* zone.

Zone of *Cyrtograptus rigidus*, Tullb.—Following the left bank of the stream, no exposures occur for some little distance, but beds are again seen where a footbridge crosses the brook; these are much softer than those previously noticed, and in consequence weather far more deeply. At the footbridge I collected the graptolites enumerated in Table III, col. B (p. 390). Although *Cyrtograptus rigidus* has not been found, the presence of *Monograptus retroflexus* and the general assemblage of forms clearly indicate the *C.-rigidus* zone. The beds here strike parallel to the stream, and dip in the same direction as before.

A little lower down the brook, similar beds are seen on the right bank. This exposure is good, but the rocks are so deeply weathered that it is hard to obtain more than mere fragments of fossils. I have been able, nevertheless, to identify the forms enumerated in Table III, col. C (p. 390). The presence of *M. retroflexus* again indicates that this exposure is in the *C.-rigidus* zone. There is a break in the succession below this point, and the next beds are seen just above where the stream bends in such wise as to run parallel with the railway. These evidently represent the base of the *C.-Lundgreni* zone.

Zone of *Cyrtograptus Lundgreni*, Tullb.—The beds seen in the above-mentioned exposure consist of calcareous shales with *Monograptus Flemingii* vars. δ & β. The list of fossils obtained is given in Table III, col. D (p. 390).

Passing under the railway, the strata of this zone are excellently exposed. The beds run very nearly parallel to the direction of the stream, but those near the railway-station are slightly higher, and the dip continues steep. I collected fossils at various points along this exposure, and these are enumerated in Table III, cols. E & F.

Slightly lower down the stream, on the right bank, *M. dubius* and *M. Flemingii* var. δ were found (see Table III, col. G). Still lower down on the right bank, the fossils found included those enumerated in Table III, cols. H & I. The rocks from which these fossils are obtained are the typical, bluish-grey, calcareous shales with harder bands.

There is again a break in the succession after a footbridge, and the next beds are seen a little lower down on the left bank. The rocks here consist of earthy calcareous flagstones, dipping S. 20° E. at 45°, and yield *M. Flemingii* var. δ and *M. dubius* (Table III, col. K, p. 390).

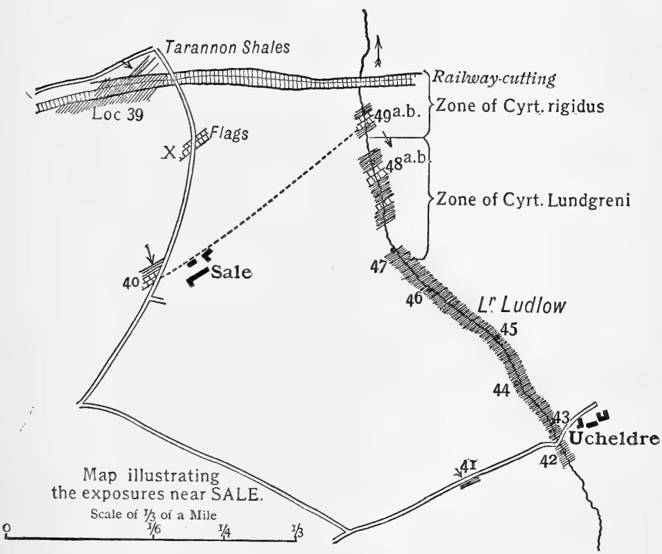
Table III. Names of Species and Varieties. [C = very common; c = common; r = somewhat rare; R = very rare.]	TREWERN BROOK GRAPTOLITES.												
	Zone of *C. Linnarssoni.*	Zone of *Cyrtograptus rigidus.*		Zone of *Cyrtograptus Lundgreni.*									
	A	B	C	D	E	F	G	H	I	K	L	M
Locality Nos. (See Map, fig. 5, p. 388.)	24	23 *c*	23 *b–a*	22 *a*	22	21 *a*	21 *c*	21 *b*	21 *a*	21	20	19
Monograptus priodon (Bronn)	c											
M. vomerinus (Nich.) var. *a*	C	...	c	...	...	...	...	C	C			
M. basilicus, Lapw.	C											
M. dubius, Suess	c	C	C	C	C	C	C	C	C	C	C	C
Cyrtograptus Linnarssoni, Lapw.	C											
Monograptus Jækeli, Perner	r											
M. retroflexus, Tullb.	...	...	C									
M. Flemingii, Salt., var. *a*	c	C	C	r								
” ” *β*	...	...	...	c	...	...	...	R				
” ” *γ*	...	...	...	...	C	C	...	C	C			
” ” *δ*	...	...	...	c	C	C	C	C	C	C	C	C
Cyrtograptus Lundgreni, Tullb.	...	...	...	...	C	C	C	C				
Monograptus irfonensis, sp. nov.	...	...	...	r								
M. testis, Barr., var. *inornatus* nov.	...	...	...	...	...	...	...	R				
Cyrtograptus tubuliferus, Perner	...	...	...	...	...	...	...	R				

The highest beds of the zone are seen in a small quarry on the right bank of a small tributary stream coming in from Glyn: these again yielded *M. dubius* and *M. Flemingii* (Table III, col. L); and similar beds occur on the right bank of the main stream, just after it is joined by this tributary (Table III, col. M). These beds are immediately succeeded in the main stream by a series of bluish-grey calcareous shales (loc. 18, fig. 5, p. 388), in which a *colonus*-like form is the predominant graptolite. They must be regarded, therefore, as the base of the Ludlow Series; they gradually give place upwards to beds in which *M. colonus, M. bohemicus,* and *M. Nilssoni* can be recognized.

(Ab) Section near Dingle Mill.

Zone of *Cyrtograptus Lundgreni*, Tullb.—This zone is exposed in the railway-cutting west of Middletown Farm, on each side of the bridge over which the road runs towards Llwyn-y-melin. The rocks consist of the typical bluish-grey shales and flags; they

Fig. 6.



dip S. 10° E. at 45°, and have yielded *C. Lundgreni, Monograptus Flemingii* var. γ, and *M. dubius*.

The upper beds of the zone are exposed in the lane leading to Dingle Mill, and in the bed of the stream which runs past the Mill. They have yielded abundant forms of *M. dubius* and a few fragments of *M. Flemingii*, probably var. δ.

There is no further exposure till near Upper Heldre, where the rocks contain an undoubted Lower Ludlow fauna.

(Ac) Section near Sale.

The lowest beds seen near Sale are the Llandovery rocks exposed near Buttington Railway-station; these are succeeded by the Purple Shales, which are splendidly exposed in the railway-cutting north of the Farm. Their relation to the overlying beds is nowhere seen, but there would seem to be considerable overlap at this point.

Zone of *Cyrtograptus rigidus*, Tullb.—In the quarry near Sale (loc. 40, fig. 6, p. 391) the beds are seen to consist of hard, pale, earthy flagstones with more shaly bands, which as a general rule are very deeply weathered. They dip S. 10° E. at an angle of about 60°, and have yielded the following fossils:—*Cyrtograptus rigidus*, *Monograptus Flemingii* var. *a*, *M. vomerinus* var. *a*, and *M. dubius*.

These beds, which undoubtedly represent the *C.-rigidus* zone, are also seen in the brook to the east which joins Trewern Brook at Trewern Bridge (Sale Brook). They are exposed on the right bank of the stream a short distance above the railway, but the exposure is poor and hard to work; consequently I did not find many graptolites, though I recognized *M. Flemingii* var. *a* and *M. dubius* (see Table IV, col. A, below).

Zone of *Cyrtograptus Lundgreni*, Tullb.—Higher up the stream a series of bluish-grey calcareous shales and flags come on, dipping S. 10° E. at an angle of 65°; in the softer beds I found the forms enumerated in Table IV, col. A. The presence of *M. Flemingii* var. δ implies that the beds belong to the *C.-Lundgreni* zone,

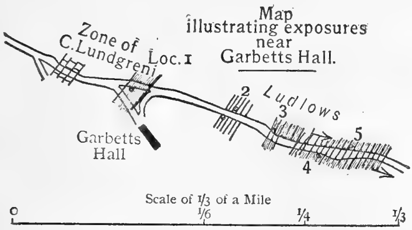
Table IV. — Names of Species and Varieties. [C = very common; c = common.]	SALE BROOK GRAPTOLITES. Zone of *C. rigidus.*	Zone of *Cyrtograptus Lundgreni.*		
	A	B	C	D
Locality Nos. (See Map, fig. 6, p. 391.).	49	48 *b*	45	47
Monograptus dubius, Suess	C	C	C	C
M. Flemingii (Salt.) var. *a*	c			
" " var. γ	...	...	C	c
" " var. δ	...	C	C	C
Cyrtograptus Lundgreni, Tullb.	...	...	C	

since that form is confined to the highest zone of the Wenlock Shales. Still farther up, where the stream is crossed by a fence, similar beds yielded the graptolites enumerated in Table IV, col. C. Above this point the exposures are continuous for some distance, but the fauna is everywhere the same.

There is a slight break in the exposure due east of Sale, though

it is continued again higher up, and beds with *M. Flemingii* vars. γ & δ and *M. dubius* are still seen (loc. 47 in fig. 6, p. 391, & Table IV, col. D). These, however, are almost immediately succeeded by beds with a *colonus*-like form belonging to the Lower Ludlow.

Fig. 7.



Map illustrating exposures near Garbetts Hall.

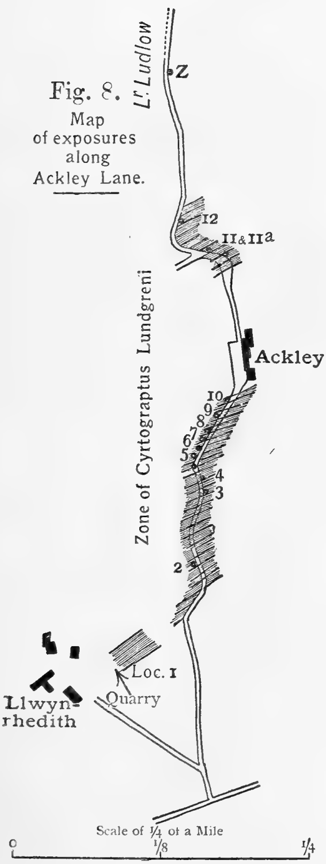


Fig. 8. Map of exposures along Ackley Lane.

(B) Section on the West Side.

Section near Garbett's Hall.

The road leading up from the Smithy near Buttington, past Garbett's Hall, affords an interesting section of the passage between the upper part of the Wenlock Shales and the Lower Ludlow Beds. Just below Garbett's Hall, where a road comes in on the right, there is a good exposure of Wenlock Shales and Flags dipping E. 10° S. at 55°, and the flags are also seen in the lane a little below. This exposure has yielded the forms enumerated in Table V, col. G (p. 395). This is obviously the zone of *Cyrtograptus Lundgreni*. Slightly higher up the lane occurs an exposure of hard flags with numerous remains of a large *colonus*-like form; while still farther up, below the fork of the road, hard calcareous flagstones are found with a typical Lower Ludlow fauna:—*Monograptus colonus, M. Nilssoni,* and *M. bohemicus*.

The other exposures on the lower slopes of the west side of the Long Mountain are of a very unsatisfactory nature. The beds dip into the hill at a high angle, and fossils are not very abundant.

Beds of undoubted Ludlow age occur near Bryn, while those exposed on the road between Leighton Church and Pentre seem to belong to the *C.-Lundgreni* zone; the rocks in the big quarry near Pentre are certainly Lower Ludlow.

(C) Sections South of the Long Mountain.

(Ca) Ackley Lane.

There is an excellent exposure in the zone of *C. Lundgreni*, in the lane near Ackley. The rocks exposed here must include almost the whole of that zone; for, as the beds sweep round the south-western extremity of the mountain, beds with the fauna of the *C.-rigidus* zone are exposed below them.

Zone of *Cyrtograptus rigidus*, Tullb. — At Kingswood several exposures occur :—in the lane, in two old quarries, and in the stream, the fauna being everywhere the same. These beds have yielded *Monograptus retroflexus*, *M. Flemingii* var. α, and *M. dubius*. The presence of *M. retroflexus* indicates the higher beds of the *C.-rigidus* zone.

Zone of *Cyrtograptus Lundgreni*, Tullb.—The section in Ackley Lane I worked in detail, with a view to determining whether any of the graptolites were characteristic of one part of the zone rather than another, and the accompanying table (Table V, p. 395) shows the result of my work. The beds present no particular features; they are merely a series of earthy calcareous shales and flags dipping W. 30° N. at a low angle. From these data it would seem that *M. Flemingii* var. γ is particularly characteristic of the lower parts of the zone, while var. δ is more abundant in the higher beds.

Above locality 12 in fig. 8 (p. 393) there is a break in the sequence of exposures; the next beds seen at Z indicate the presence of the Lower Ludlow.

Exposures belonging to the *C.-Lundgreni* zone are seen at several points along the road that runs from Marton through Worthen and on to Westbury. The beds are well exposed at Marton close to the church, where I collected *M. Flemingii* vars. γ & δ and *M. dubius*: these are probably the lower beds of the zone.

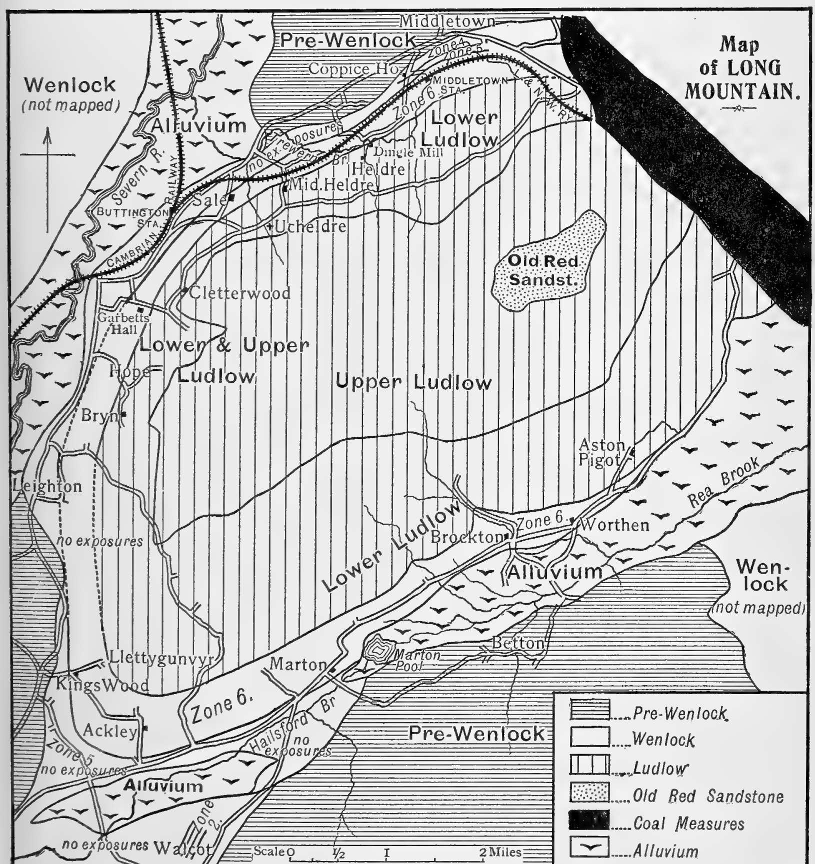
Higher beds are seen on the top of the hill before Brockton village is reached, in Brockton Brook, and also west of Worthen. East of Worthen the zone gradually passes beneath the alluvium, for beds with a characteristic Lower Ludlow fauna are seen in a field immediately above the road at the Plough Inn, and all the other exposures examined farther east were in beds of that age.

(Cb) Walcot Quarry.

The lowest Wenlock Beds seen in the district are exposed north

TABLE V. Names of Spp. and Vars. [C=very common; c=common; r=somewhat rare; R=very rare.]	ACKLEY LANE GRAPTOLITES. Zone of *Cyrtograptus Lundgreni.*											
	A	B	C	D	E	F	G	H	I	K	L	M
Locality Nos. (See Map, fig. 8.)	1	2	3	4	5	6	7	8	9	10	11	12
Monograptus dubius, Suess.	C	C	C	C	...	...	C	...	C	C	C	C
M. Flemingii (Salt.) var. *α*	?											
" " var. *β*	R	R										
" " var. *γ*	C	C	C									
" " var. *δ*	...	...	r	c	C	C	C	C	C	C	C	c
Cyrtograptus Lundgreni, Tullb.	C	C	...	...	...	...	...	...	C	...	C	C
C. Carruthersi, Lapw.	...	...	r	r	C	C	...	c	...	...	...	C
M. testis (Barr.) var. *inornatus* nov.	...	...	...	...	...	R						
M. colonus-type	...	...	...	...	...	...	...	...	...	...	...	r

Fig. 9.



of Chirbury, in a quarry behind Walcot Farm. Here the beds consist of a series of earthy calcareous shales and flags dipping W. 10° N. at 15°; they are richly fossiliferous, and evidently belong to the zone of *Monograptus riccartonensis*, Lapw. The type-fossil is extremely abundant. These beds have yielded *Cyrtograptus flaccidus*, Tullb., *Cyrtogratus* sp., *M. riccartonensis*, *M. capillaceus*, *M. dubius*, *M. vomerinus*, and *M. priodon*. (See Table VI, col. A.)

Table VI. Names of Species and Varieties.	LONG MOUNTAIN GRAPTOLITES.								
	Zone of *M. riccartonensis.*	Zone of *C. Linnarssoni.*	Zone of *Cyrtograptus rigidus.*			Zone of *Cyrtograptus Lundgreni.*			
	A	B	C	D	E^1	E^2	F	G	H
[C = very common; c = common; r = somewhat rare; R = very rare.] NOTE—The zone of *C. symmetricus* is not exposed in the district.	Walcot.	Coppice House.	Kingswood.	Sale Farm.	Sale Brook.	Sale Brook.	Dingle Mill.	Garbett's Hall.	Marton.
Monograptus priodon (Bronn) ...	c	r							
M. vomerinus (Nich.) var. *α*	C	c	...	C	C				
M. riccartonensis, Lapw.	C								
M. capillaceus, Tullb.	C								
Cyrtograptus flaccidus, Tullb. ...	C								
Monograptus dubius, Suess	c	C	C	C	C	C	C	C	C
Cyrtograptus Linnarssoni, Lapw.	...	C							
Monograptus Jækeli, Perner	...	r							
Cyrtograptus rigidus, Tullb.	...	...	...	C					
Monograptus retroflexus, Tullb.	...	...	C						
M. Flemingii (Salt.) var. *α*	...	c	C	C	C				
" " var. *β*	...	...	...	...	...	...	?		
" " var. *γ*	...	...	...	...	...	C	C	C	C
" " var. *δ*	...	...	...	...	...	C	C	C	C
Cyrtograptus Lundgreni, Tullb. ...	...	...	...	...	...	C	C	C	
M. testis (Barr.) var. *inornatus* nov.	...	...	...	...	...	...	...	R	
Cyrtograptus tubuliferus, Perner...	...	...	...	...	...	...	...	R	

The exposure occurs exactly where it might naturally be expected that the *M.-riccartonensis* zone would lie: that is, a little way above the base of the Wenlock Shales, as mapped by the officers of the Geological Survey. So far as I have been able to discover, the earlier zone of *Cyrtograptus Murchisoni* is not exposed in the Long Mountain area, unless it be represented by some of the shales near The Stubbs, where, as I have already pointed out, the beds are apparently unfossiliferous. This zone, however, is so

persistent elsewhere, that it is not unlikely that it occurs in proper sequence in this district.

It is evident from the facts collected and noted in the foregoing pages, that the sections in the Long Mountain, so far as they go, are in full accord with the succession made out in the Builth District, both as regards the nature of the rocks and the sequence of the fossils.

The presence of the Purple Shales in the north, lying so close to the beds of Middle Wenlock-Shale age (*M.-Linnarssoni* zone) seems to point to considerable overlap in this part of the Long-Mountain area; though, as in the case of the earlier beds, it is hard to detect it apart from the palæontological evidence.

In the south the succession is probably complete, at any rate down to the bottom of the *M.-riccartonensis* zone, though the Middle Wenlock zones are all concealed by alluvial deposits.

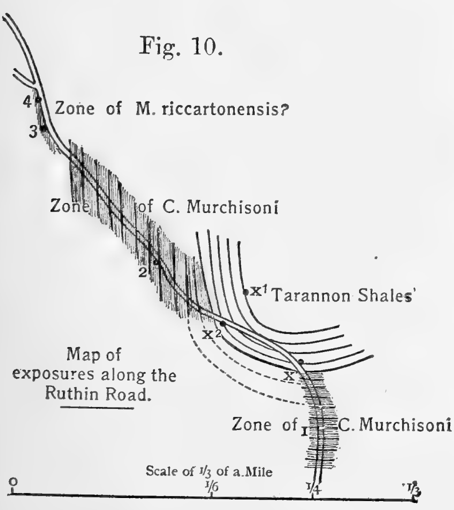
V. The Dee Valley.

In the Llangollen Basin the lower zones of the Wenlock Shales are exposed in several localities, where their relation to the underlying Tarannon Shales is clearly shown. The general structure of the district is a syncline, complicated by many minor folds and by faults.

(*a*) Ruthin Road-Section.

The relationship to the Tarannon Shales is perhaps best seen on the road from Llangollen to Ruthin, about 1 mile north of Pentredwfr; here is an excellent section exposed for some little distance, the basal Wenlock Shales being easily recognized and distinguished from the Tarannon Shales, on account of their very different lithological character.

Fig. 10.



The beds which lie immediately above the 'Pale Slates' are soft and weather deeply: they are succeeded, however, by others which are harder and much more slaty in character. At the junction with the Tarannons a few pale bands appear to alternate with the darker Wenlock Shales, but these soon disappear.

The basal Wenlock rocks at this locality contain the fauna enumerated in Table VII, col. A (p. 399), an assemblage which indicates the zone of *Cyrtograptus Murchisoni*. The greater part of this road-section is occupied by the *C.-Murchisoni* zone, except where the Tarannons cross the road. Near the summit of the hill, however, the *M.-riccartonensis* zone seems to begin, though only a small portion of it is exposed.

(*b*) Caer Drewyn.

The relation of the basal Wenlocks to the Tarannon Shales is also well seen on the western slopes of Caer Drewyn, north of Corwen, and in the small brook which runs a little east of Tomen-y-Meirw.

On Caer Drewyn the base of the hill appears to be occupied by light Tarannon Shales. Slightly higher up these pale slates are seen to alternate with dark blue shaly bands, which become gradually more abundant, and finally attain a considerable thickness, containing the characteristic fossils of the *C.-Murchisoni* zone. These shales are well exposed in an old trial-working on the hill-side; they have yielded *C. Murchisoni*, *Monograptus priodon*, and *M. vomerinus*. (See also Table VII, col. B, p. 399.)

Farther north another trial-working has been made in beds of a still higher horizon than that of the *M.-riccartonensis* zone; the beds contain, besides *M. riccartonensis*, *M. priodon* and *M. vomerinus*. The Pen-y-glog Grit succeeds the higher of these zones and occupies the whole of the hilltop.

(*c*) Stream East of Tomen-y-Meirw.

In the stream east of Tomen-y-Meirw the basal Wenlock Shales are also well exposed, showing alternations with pale slate-bands near the junction with the Tarannons. They are not, however, very fossiliferous here, and are soon faulted out against the Moel Ferna Slates, which belong to the upper part of the series.

(*d*) Penarth Quarry.

Nowhere, in any single locality known to me, is the relation of the *Cyrtograptus-Murchisoni* and *Monograptus-riccartonensis* zones better seen than in the big quarry at Penarth (Pen-y-glog), where the upper zone has been extensively quarried for slate.

The beds in the quarry dip north-eastward, and at the south-western extremity the lower beds of bluish-grey calcareous slate are well seen, swarming with fairly preserved specimens of *C. Murchisoni* and other forms characteristic of this horizon, such as *M. priodon*, *M. vomerinus* var. *a*, and *Retiolites Geinitzianus*, Barr. (See also Table VII, col. C^1, p. 399.)

The base of this zone is not seen; but, as the Tarannon Shales come on a little farther westward, the beds cannot be very high up in the series.

In the higher horizons of the zone *Monograptus riccartonensis* makes its appearance, and in the beds overlying these it occurs to the exclusion of almost every other form, huge slabs of slate crowded with this graptolite being very common. It is abundant throughout the best slate-beds, and seems only to disappear when these are succeeded by the Pen-y-glog Grit. The Grit occupies a fairly wide area south-east of Penarth Quarry, and on the eastern flanks of Moel Ferna another series of hard slates is exposed: these are extensively quarried. The lower beds evidently belong to the zone of *Cyrtograptus Linnarssoni*, since they contain that fossil in fair abundance and also the forms enumerated in Table VII, col. E.

The beds that overlie the foregoing are not very fossiliferous; they contain only a few specimens of *M. dubius* and *M. Flemingii* var. (?). The highest Wenlock Shales seen are exposed in a small trial-working farther east, and these yield, in addition to the two forms just mentioned, a *colonus*-like form: therefore they are probably quite near the top of the series.

The slates which succeed these beds are extensively quarried in the Deeside Slate Quarries, and are undoubtedly of Lower Ludlow age, since they contain *M. colonus*, *M. Nilssoni*, and *M. bohemicus*.

TABLE VII.	DEE VALLEY GRAPTOLITES.							
Names of Species and Varieties.	Zone of *Cyrtograptus Murchisoni.*			Zone of *Monograptus riccartonensis.*		Zone of *C. Linnarssoni.*	Zone of *C. rigidus.*	Zone of *C. Lundgreni.*
[C = very common; c = common; r = somewhat rare; R = very rare.]	A	B	C^1	C^2	D	E	F	G
Note.—There is no palæontological evidence of the *C.-symmetricus* zone in the Dee Valley.	Ruthin Road.	Caer Drewyn.	Penarth.	Penarth.	Glyn.	Moel Ferna.	Moel Ferna.	Moel Ferna.
Monograptus priodon (Bronn)	C	C	C	c	c	r		
Retiolites Geinitzianus, Barr.	C	C	C					
Cyrtograptus Murchisoni, Carr.	C	...	C					
Monograptus vomerinus (Nich.) var. *a*.	C	C	C	...	...	c		
M. basilicus, Lapw.	c	...	...	...	...	c		
M. riccartonensis, Lapw.	R	R	R	C	C			
M. dubius (Suess)	...	...	...	...	c	C	C	C
Cyrtograptus Linnarssoni, Lapw.	...	...	...	...	...	C		
Monograptus flexilis, sp. nov.	...	...	...	...	...	C		
M. Flemingii (Salt.) var. *a*	...	...	...	...	...	c	c	
,, ,, γ	...	...	...	...	...	...	...	C
,, ,, δ	...	...	...	...	...	...	...	c

Table VIII.—Correlation of the Upper Silurian of the Welsh Borderland with that of Southern Sweden.

BUILTH.	LONG MOUNTAIN.	DEE VALLEY.		SOUTHERN SWEDEN.
Lower Ludlow.	Lower Ludlow.	Nant-Glyn Flags.		*Cardiola*-Shales.
Zone of *Cyrtograptus Lundgreni*, Tullb.	Zone of *C. Lundgreni* ...	Moel Ferna Slates.	Slates with very few graptolites.	Zone of *C. Carruthersi*, Lapw. = Zone of *Monograptus testis*.
Zone of *Cyrtograptus rigidus*, Tullb.	Zone of *C. rigidus*			Zone of *Cyrtograptus rigidus*.
Zone of *Cyrtograptus Linnarssoni*, Lapw. ...	Zone of *C. Linnarssoni* ...		Zone of *C. Linnarssoni*.	
Zone of *Cyrtograptus symmetricus*, sp. nov. ...	(?)	Pen-y-glog Grit.		Zone of *Monograptus riccartonensis*.
Zone of *Monograptus riccartonensis*, Lapw. ...	Zone of *M. riccartonensis*	Pen-y-glog Slates.	Zone of *M. riccartonensis*.	
Zone of *Cyrtograptus Murchisoni*, Carr.	(?)		Zone of *C. Murchisoni*.	Zone of *C. Murchisoni*.
Local unconformity. (Tarannon Shales ?). Llandovery Grits.	Local unconformity. Purple Shales (? Tarannon). Llandovery Grits.	Conformable succession. Tarannon Shales. Corwen Grit.		Conformable succession. Shales with graptolites.

VI. General Conclusions, and Correlation of the Beds of the Welsh Borderland with their Foreign Equivalents.

We have now completed our examination of the arrangement of the strata and the distribution of the graptolites in three of the most important areas of Wenlock rocks in the Welsh Borderland, namely, the Builth District, the Long Mountain, and the Dee Valley. The beds are not equally developed in the three areas; the succession is most complete at Builth, but the upper beds are best developed in the Long Mountain, and the relationship of the lowest beds is clearest in the Dee Valley. In all three cases, however, the lithological and palæontological evidence is in full accord.

The various species of graptolites which are met with in the strata of each area group themselves into an ascending succession of recognizable graptolitic sub-faunas, which in all three districts are the same. It must therefore, I think, be admitted that the Wenlock Shales of the Welsh Borderland, like those of Southern Sweden, are capable of a zonal classification, using the characteristic graptolites as zone-indices. The accompanying table (VIII, p. 400) indicates the zones present in each area and their correlation with the beds in Southern Sweden.

The two lowest zones of the Welsh Borderland and the highest are apparently present in Bohemia also, for I have collected the typical fossils there, although I am not aware that detailed mapping of the zones has yet been done for that country. In Sweden and Bohemia the typical fossil of the highest beds is *Monograptus testis*, but in our own country the most widespread form is certainly *Cyrtograptus Lundgreni*, and therefore I have chosen it for my zone-fossil. The true *M. testis* of Barrande has not yet been recorded in this country. *Cyrtograptus Carruthersi*, which is used by Tullberg as a zone-fossil, is not very abundant, and is liable to be confused with *Monograptus Nilssoni* of the Lower Ludlow.

VII. Palæontology.

The graptolite-fauna of the Wenlock Shales is rather monotonous; in all, there are not more than four genera represented, and the number of species (including varieties) does not exceed thirty.

The *Cyrtograpti* attain their maximum development in these beds, though they are certainly found in lower beds, and one species perhaps passes up into the Lower Ludlow. The *Monograpti* are also abundant, though the number of species represented is far less numerous than in the earlier horizons. Several Continental forms already recognized in Sweden are here recorded from this country, for the first time; with regard to others previously recorded as occurring in Britain, some notes are necessary. A few new species have been obtained, and these are described in detail.

Description of the Species.

1. Genus *Monograptus*, Geinitz.

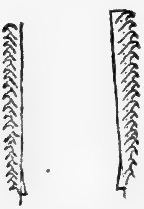
Monograptus Flemingii (Salt.).

Salter, Quart. Journ. Geol. Soc. vol. viii (1852) p. 390 & pl. xxi, figs. 5 *a–b*, 6, 7 *a–b*; Lapworth, 'Scottish Monograptidæ' Geol. Mag. 1876, p. 504 & pl. xx, fig. 8; Tullberg, 'Skånes Graptoliter' pt. ii (1883) Sver. Geol. Undersökn. ser. C, no. 55, p. 23 & pl. ii, fig. 25.

Some of the forms originally united by Salter under this title have been separated by Lapworth as *M. riccartonensis*; those in which the rhabdosoma was broadest and the thecæ more numerous were retained as *M. Flemingii*. Good descriptions of these forms are given by Lapworth and Tullberg (*op. cit.*) They are allied to *M. priodon* (Bronn), but may be readily distinguished from that species by the backward curvature of the proximal end and the character of the thecal apertures.

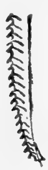
In my work among the Wenlock Shales I have found that there are four different varieties of this species, which are characteristic of different horizons, and these I have called in my lists of fossils vars. α, β, γ, δ, denoting the order of their appearance. The chief difference in the varieties is usually to be found at the proximal end.

Fig. 11.—M. Flemingii, *var.* α, *from Dulas Brook and Nant Prophwyd.*



[Nat. size.]

Fig. 12.—M. Flemingii, *var.* β, *from Dulas Brook.*



[Nat. size.]

Var. α. (Text-fig. 11.)

Greatest length observed = $1\frac{1}{2}$ inches (37·5 mm.). Common form only $\frac{2}{3}$ inch (17·6 mm.) long. Length of sicula = $\frac{1}{16}$ inch (1·587 mm.). Outer wall decidedly curved, giving the appearance of a backward curvature to the extreme proximal end of the rhabdosoma; inner wall straight. Virgella directed obliquely backward. Thecæ varying in number in different parts of the rhabdosoma, for first $\frac{1}{4}$ inch = thirty-six to the inch (fourteen in 10 mm.), first $\frac{1}{2}$ inch twenty-eight (eleven in 10 mm.), $\frac{3}{4}$ inch twenty-four (nine in 10 mm.), $1\frac{1}{4}$ inches twenty (eight in 10 mm.); narrow proximally, but increasing steadily up to a maximum width of $\frac{1}{10}$ inch (2·54 mm.). Virgula not distally prolonged.

Var. β. (Text-fig. 12.)

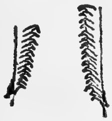
Closely allied to the foregoing, but the whole of the proximal end has a decided curvature, both the inner and outer walls of the sicula being curved.

Var. γ. (Text-fig. 13, p. 403.)

A small compact form, very rarely exceeding 1 inch in

length. Length of sicula = $\frac{1}{16}$ inch (1·587 mm.). Outer wall curved, inner straight. Thecæ closely set throughout, numbering as many as forty-four to the inch (seventeen in 10 mm.) near the sicula. The rhabdosoma widens very rapidly to a maximum width of $\frac{1}{8}$ inch (3·174 mm.).

Fig. 13.—M. Flemingii, *var. γ, from the R. Irfon and Ackley.*



[Nat. size.]

Var. δ. (Text-fig. 14.)

An exceedingly long form, often attaining a length of 7 or 8 inches (175 mm.). The whole rhabdosoma is irregularly curved, and decidedly so near the proximal end. The rhabdosoma widens slowly up to a maximum of $\frac{1}{10}$ inch (2·54 mm.). The number of thecæ varies in different parts of the rhabdosoma, but is never less than twenty-four to the inch (nine or ten in 10 mm.).

Fig. 14.—M. Flemingii, *var. δ, from the Irfon.*

[Nat. size.]

Var. α makes its first appearance in the zone of *Cyrtograptus symmetricus* (where it is very rare), and attains its maximum development in the zone of *C. rigidus*, where var. β appears.

Var. β is never a common form, but it is also found in the succeeding zone. The characteristic little variety γ is practically confined to the base of the *C.-Lundgreni* zone, and is very abundant there; while var. δ, which appears at the same time, attains its maximum development in the higher parts of that zone, and is very occasionally to be met with at the base of the Lower Ludlow.

The accompanying table (IX, p. 404) illustrates the chief characteristics of these varieties.

Monograptus vomerinus (Nich.).

Nicholson, 'Monogr. Brit. Graptolitidæ' 1872, p. 53, fig. 21; Lapworth, 'Scottish Monograptidæ' Geol. Mag. 1876, p. 353 & pl. xii, figs. 6 *a–e*; Tullberg, 'Skånes Graptoliter' pt. ii (1883) Sver. Geol. Undersökn. ser. C, no. 55, p. 19 & pl. ii, figs. 10–11; Perner, 'Etudes sur les Graptolites de Bohême' pt. iii, sect. *b* (1899) p. 18 & pl. xiv, figs. 2 *a–c* & fig. 20, pl. xvi, figs. 1–3, pl. xvii, fig. 13.

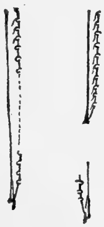
There appear to be three graptolites of the type of *Monograptus vomerinus* (Nich.) present in the zone of *Cyrtograptus Murchisoni*, though the third has not been found by me in the districts with which this paper deals.

TABLE IX.—CHARACTERISTICS OF THE VARIETIES OF *MONOGRAPTUS FLEMINGII*.

Var.	Localities.	Horizons.	Length.	Maximum width.	No. of thecæ (proximal).	No. of thecæ (distal).	Length of sicula.	Character of proximal end.
α	Builth Road; Dulas Brook; and Nant Prophwyd.	Zones of *Cyrtograptus Linnarssoni* and *C. rigidus*.	$\frac{3}{4}$ to $1\frac{1}{2}$ inches (25·4 to 37·5 mm.).	$\frac{1}{16}$ to $\frac{1}{10}$ inch (1·587 to 2·54 mm.).	36 to 40 in 1 in. (14 to 16 in 10 mm.).	24 in 1 inch (9 to 10 in 10 mm.).	$\frac{1}{16}$ inch (1·587 mm.).	Inner dorsal wall straight.
β	Nant Prophwyd and Llwynrhedith.	Zones of *Cyrtograptus rigidus* and *C. Lundgreni*.	$\frac{5}{12}$ to $\frac{5}{6}$ inch (10·5 to 21 mm.).	$\frac{1}{16}$ to $\frac{1}{10}$ inch widens gradually (1·587 to 2·54 mm.).	36 in 1 inch (14 to 15 in 10 mm.).	28 in 1 inch (11 in 10 mm.).	$\frac{1}{16}$ inch (1·587 mm.).	Dorsal wall curved for three thecæ.
γ	Llwynrhedith and River Irfon.	Zone of *Cyrtograptus Lundgreni* (lower part).	$\frac{3}{4}$ to 1 inch (19·04 to 25·4 mm.).	$\frac{1}{10}$ to $\frac{1}{8}$ inch widens rapidly (2·54 to 3·174 mm.).	40 to 44 in 1 in. (16 to 17 in 10 mm.).	32 in 1 inch (12 to 13 in 10 mm.).	$\frac{1}{16}$ inch (1·587 mm.).	Dorsal wall straight.
δ	River Irfon; Ackley Lane; Aberedw Hill, etc.	Zone of *Cyrtograptus Lundgreni*.	$1\frac{1}{2}$ to 7 inches (37·5 to 175 mm.).	$\frac{1}{12}$ to $\frac{1}{10}$ inch (2·1 to 2·54 mm.).	36 in 1 inch (14 in 10 mm.).	24 in 1 inch (14 in 10 mm.).	$\frac{1}{16}$ inch (1·587 mm.).	Dorsal wall curved throughout its length.

The distal parts of these are almost indistinguishable, but the proximal end of each form is quite distinct. The characteristics of the proximal end are as follows:—

Fig. 15.—M. vomerinus, *var. α, from Pencerrig.*

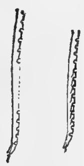


[Nat. size.]

1. Var. α. (Text-fig. 15.)

A form with a sicula nearly $\frac{1}{12}$ inch (2·1 mm.) in length, the apex of which reaches up to the aperture of the first theca. The inner wall of the sicula forms a straight line with the dorsal wall of the polypary; the outer wall is curved slightly backward. The increase in width is fairly rapid; the first theca is very long.

Fig. 16.—M. vomerinus, *var. β, from Pencerrig.*



[Nat. size.]

2. Var. β. (Text-fig. 16.)

A form with a short sicula which never exceeds $\frac{1}{20}$ inch (1·27 mm.) in length. All the thecæ are short and closely set in the proximal part, and the whole proximal end is curved backward. This variety widens very gradually; the sicula reaches the first thecal aperture.

Fig. 17.—M. vomerinus, *var. γ, from Conway.*

[Nat. size.]

3. Var. γ. (Text fig. 17.)

Form with a sicula about $\frac{1}{16}$ inch (1·587 mm.) in length, but the first theca is so short that the apex of the sicula is on a level with the second thecal aperture. The outer wall of the sicula forms a straight line with the dorsal wall of the polypary.

Var. α seems to be closest to Nicholson's species, though the character of the proximal end also closely resembles Törnquist's form *crenulatus*, but the thecal apertures in this last species are very much smaller in proportion to the width of the polypary, and the thecæ are shorter. Var. α is certainly the commonest of the three varieties. Vars. β and γ are but rarely met with outside the *Cyrtograptus-Murchisoni* zone. The accompanying table (X, p. 406) illustrates the variations in this form.

Monograptus flexilis, sp. nov. (Text-fig. 18, p. 407.)

Rhabdosoma long and very flexible. Maximum length observed =9 inches (about 22·5 cm.), but smaller forms are more common. Curvature variable in amount, but always great at the proximal end. The long forms seem to make a complete double curve.

Sicula small and broad, $\frac{1}{20}$ inch (1·27 mm.) in length, furnished

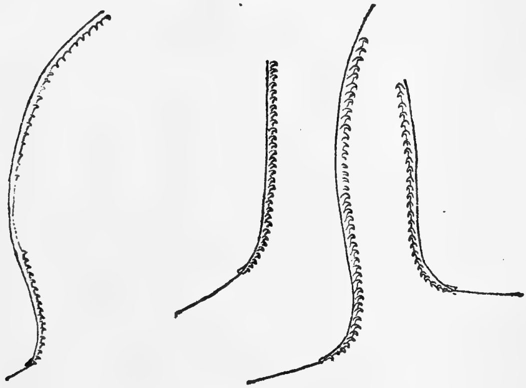
TABLE X.—CHARACTERISTICS OF THE VARIETIES OF *MONOGRAPTUS VOMERINUS*.

Var.	Localities.	Horizons.	Length.	Maximum width.	No. of thecæ (proximal).	No. of thecæ (distal).	Length of sicula.	Character of proximal end.
α	Pencerrig, Trecoed, River Irfon, etc.	Zone of *Cyrtograptus Murchisoni* to zone of *C. Lundgreni*.	$\frac{1}{2}$ to 3 inches (12·7 to 76·2 mm.).	$\frac{1}{16}$ to $\frac{1}{12}$ inch, rapid (1·587 to 2·1 mm.).	24 in 1 inch (9 in 10 mm.).	24 in 1 inch (9 to 10 in 10 mm.).	$\frac{1}{16}$ inch (1·587 mm.).	Outer wall of sicula slightly curved, inner wall straight; first theca very long.
β	Pencerrig.	Zone of *Cyrtograptus Murchisoni*.	$\frac{1}{4}$ to 1 inch (6·35 to 25·4 mm.).	$\frac{1}{24}$ to $\frac{1}{16}$ inch, very gradual (1·05 to 1·587 mm.).	28 to 32 in 1 inch (11 to 13 in 10 mm.).	24 in 1 inch (9 to 10 in 10 mm.).	$\frac{1}{20}$ inch (1·27 mm.).	Proximal end curved backward.
γ	Conway District.	Zone of *Cyrtograptus Murchisoni* and possibly higher zones.	$\frac{1}{8}$ inch (3·174 mm.).	$\frac{1}{24}$ inch (1·05 mm.).	30 to 32 in 1 inch (12 to 13 in 10 mm.).	24 in 1 inch (9 to 10 in 10 mm.).	$\frac{1}{16}$ inch (1·587 mm.).	Apex of sicula on a level with the second thecal aperture; first theca short.

with a long and stout virgella, which is often 1 inch long (25 mm.). The rhabdosoma widens rapidly from its origin for the first $\frac{1}{2}$ inch (12·5 mm.), and then slowly for the remainder of its length.

Width at origin	$\frac{1}{24}$ inch (1·05 mm.).
Width at $\frac{1}{2}$ inch from origin............	$\frac{1}{16}$ inch (1·587 mm.).
Maximum width	$\frac{1}{12}$ inch (2·1 mm.).

Fig. 18.—Monograptus flexilis, *sp. nov., from Moel Ferna.*



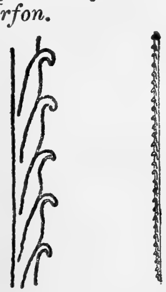
[Nat. size.]

The virgula is often prolonged distally, especially in young forms. The thecæ are of the normal *Flemingii*-type, and agree with that species in inclination, being inclined to the axis at 40°; the first thecal aperture is on a level with the apex of the sicula, and the thecæ number twenty-two to twenty-four in the inch (eight or nine in 10 mm.). The species is allied to the members of the *Flemingii-riccartonensis* group, but differs in the amount of curvature of the rhabdosoma and in the presence of the long virgella.

Horizon.—Zone of *Cyrtograptus Linnarssoni*, Lapw.

Localities. — Moel Ferna, Slate Quarries. Stream south of Tomen-y-Meirw.

Fig. 19.—M. irfonensis, *sp. nov., from the R. Irfon.*



b [×5.] *a* [Nat. size.]

Monograptus irfonensis, sp. nov. (Text-fig. 19.)

Rhabdosoma very slender, rigid, straight, attaining a length of 8 inches. Sicula small, inconspicuous, $\frac{1}{25}$ inch (1·01 mm.) long; rhabdosoma very narrow at the origin, increasing slowly up to a maximum of $\frac{1}{24}$ inch (1·05 mm.).

Thecæ very long and narrow, in contact for half their length,

tubular in form with reflexed apertures; inner wall straight or very slightly curved, outer wall bent into an elongated slight double curve. The thecæ are inclined at 10°, and number twenty-three to the inch (eight or nine in 10 mm.).

This species is allied to *M. scanicus*, Tullb., but differs in the absence of curvature of the rhabdosoma and in the number of thecæ in a given unit of length.

Horizon.—Zone of *Cyrtograptus Lundgreni.*

Localities.—River Irfon; Trewern Brook.

Monograptus testis (Barr.) var. *inornatus* nov. (Text-fig. 20).

The true *M. testis* has not yet been recorded from this country, and this variety has only been found by Prof. Watts and myself in the Long Mountain district. In general appearance (curvature, etc.) the variety agrees closely with the typical form, but the characters of the thecæ are very different.

Fig. 20.—M. testis, *var.* inornatus *nov.*

[Nat. size.]

They present in general the form characteristic of *M. Flemingii*, that is, a lobed apertural part furnished with a short denticle. In the typical form the apertures are slightly concave and furnished with very long spines, which appear to be entirely absent in the English variety.

In addition the thecæ are more closely set than in the type, being as many as thirty-six to the inch (nearly fifteen in 10 mm.), against twenty-five in the typical form (ten in 10 mm.).

Horizon.—Zone of *Cyrtograptus Lundgreni.*

Localities.—Trewern Brook; Garbett's Hall; Ackley Lane.

2. Genus *Cyrtograptus*, Carruthers.

Cyrtograptus Carruthersi, Lapw. = (?) *Monograptus Nilssoni* (Barr.). (Text-figs. 21 & 22, p. 409.)

Lapworth, 'Scottish Monograptidæ' Geol. Mag. 1876, p. 321 & pl. x, figs. 6 *a–c*.
Tullberg, 'Skånes Graptoliter' pt. ii (1883) Sver. Geol. Undersökn. ser. C, no. 55, p. 37 & pl. iv, figs. 15–18, also pl. iii, fig. 25.

The species *M. Nilssoni* was originally figured and described by Barrande in 1850 in his classical work the 'Graptolites de Bohême,' p. 51 & pl. ii, figs. 16, 17 & 18. Lapworth pointed out in 1876 (*op. cit.*) that more than one species has been figured by Barrande under this title, and he stated that fig. 16 of pl. ii was the only one to which the diagnosis fully applied. In 1883 Tullberg (*op. cit.* p. 17 & pl. i, figs. 31, 32) followed Lapworth in taking Barrande's fig. 16 as the type-form, but he also regarded fig. 17 as belonging to the species. More recently Perner[1] has pointed out that Barrande's three original figures stand for three distinct species. Barrande's fig. 17 he referred to Tullberg's *Cyrtograptus Lundgreni*, and fig. 18 he identified with his own

[1] 'Graptolites de Bohême' pt. iii, sect. *b* (1899) p. 7 & pl. xvii, figs. 1, 2, 7.

species *Cyrtograptus tubuliferus*, while he regarded fig. 16 as the type-form of Barrande's *Monograptus Nilssoni*.

In the Riccarton (Wenlock) Beds of Southern Scotland occurs a graptolite, which agrees with this type-specimen of *M. Nilssoni*, except in the matter of branching; this is Lapworth's *Cyrtograptus Carruthersi*. Through the kindness of Prof. Lapworth I append here a figure of one of the type-specimens of his species, together with an example of *M. Nilssoni*. A similar form was collected by myself from the typical locality of Borek, in Bohemia, where *C. Lundgreni*, *M. Nilssoni*, and *M. testis* are found to occur on the same slab of rock.

Fig. 21.—Cyrtograptus Carruthersi. Fig. 22.—Monograptu Nilssoni.

[Nat. size.]

It will be evident that the two forms *M. Nilssoni* and *C. Carruthersi* differ merely in regard to the matter of branching. This branching form, *C. Carruthersi*, is a Wenlock fossil, and is fairly characteristic of the highest beds of the Wenlock Shales, while *M. Nilssoni* is a typical form of the succeeding Lower Ludlow Beds.

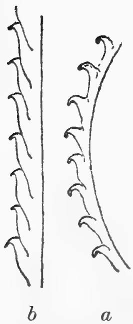
It may be frankly admitted that *C. Carruthersi* is in all probability the immediate ancestor of *M. Nilssoni*, if not identical with it. But bearing in mind, on the one hand, that the branching forms referred to *Cyrtograptus* are of the greatest importance as Wenlock zonal indices, and on the other, that our knowledge of the cause and meaning of the branching in the Monograptids is as yet incomplete, it is not my purpose at present to suggest a change in the accepted nomenclature.

Cyrtograptus rigidus, Tullb. (Pl. XXIV, figs. 2 A, B, C, & text-fig. 23, p. 410).

Tullberg, 'Skånes Graptoliter' pt. ii (1883) Sver. Geol. Undersökn. ser. C, no. 55, p. 38 & pl. iv, figs. 12–14.

Our British specimens do not agree exactly with Tullberg's description, as there are many more thecæ in the proximal part of the rhabdosoma, but though Tullberg gives the number of proximal thecæ as six or seven, none of his figured specimens are complete. They certainly show six or seven proximal cells, but there is no sign of a sicula, nor is there any indication of the decided attenuation which is commonly, indeed almost universally, characteristic of this genus in the region of the sicula. I have noticed that it is a common occurrence for specimens to be broken, leaving only six or seven thecæ below the branch, but am unable to account for this. The thecæ are inclined at an angle of about 20°. Tullberg's

Fig. 23.—Cyrtograptus rigidus.



b a

a = proximal type of cell, × 5.

b = type of cell of branch (in relief), × 5.

Fig. 24.—Cyrtograptus Lundgreni.

b a

a = proximal type of cell, × 5.

b = type of cell of branch, × 5.

[For comparison with *C. rigidus*.]

figures also show this latter inclination (*op. cit.* pl. iv, figs. 12 & 14).

I append a brief description of the proximal part of the rhabdosoma, as supplementary to the description which Tullberg has already given :—

Sicula very small and inconspicuous; rhabdosoma very narrow at the origin, gradually increasing in width up to the point of origin of the only branch. Proximal thecæ triangular, with slightly reflexed apertures, in contact only, numbering twenty-four to the inch (nearly ten in 10 mm.). There are eighteen thecæ of proximal type, but only thirteen before the branch is given off.

The proximal end is straight; it is never enrolled.

Localities.—Dulas Brook; River Irfon; Sale.

Cyrtograptus symmetricus, sp. nov. (Pl. XXIV, figs. 4 A & 4 B.)

Rhabdosoma unilateral, monoprionidian, with a slender proximal part, but the distal part often attains a width of fully $\frac{1}{16}$ inch (1·587 mm.). One branch only is present, and its curvature is similar in amount, but opposite in direction, to that of the main stipe. The curvature of both lateral and main stipes is slight, but elegant.

The first theca arises from the base of a small sicula $\frac{1}{24}$ inch (1·05 mm.) in length. The first eight cells are similar in character: they are fairly large and triangular, with reflexed apices; the thecæ are in contact only, and number twenty-four to the inch (nearly ten in 10 mm.).

The branch originates with the fifth or sixth theca, and the subsequent change in the character of the cells is very abrupt.

After the eighth theca the thecæ are tubular, with reflexed apices furnished with distinct denticles. The thecæ overlap one third of their length, and are inclined at an angle of 20° to 25°; the apertural angle is about 130°, and the cells number twenty-six to twenty-eight in the space of an inch (eleven in 10 mm.). The thecæ are seen to be situated on the concave side of the main stipe, which, immediately after the branch is given off, quickly widens to $\frac{1}{16}$ inch (1·587 mm.). The branch is the exact counterpart of the distal portion of the main stipe, differing only in direction of growth.

No further branching has been observed, though the main stipe has been seen for 2 inches (50 mm.) after the branch is given off.

In its proximal part this species is not unlike *Cyrtograptus Linnarssoni*, Lapw., the branch being given off at the same distance from the sicula, but the general form, absence of pronounced curvature, direction of curvature of branch, and character of the thecæ in the adult parts easily distinguish it from that species. In general form it is not unlike *C. rigidus*, Tullb., but differs from that species in the character of the proximal end and the number of thecæ in the adult portions of the stipes.

Characteristics:—

(1) General form and presence of only one branch.
(2) Number of thecæ to the inch in the distal part of the main stipe and branch.
(3) Abrupt widening and general width of the adult part, as compared with the proximal portions of the rhabdosoma.

Horizon.—Zone of *Cyrtograptus symmetricus*.

Localities.—Builth Road; Coed Mawr; Castle Crab.

Table XI.—Distribution of Species in the Wenlock Shales.

Names of Species. [C = very common; c = common; r = somewhat rare; R = very rare.]	Zone of *C. Murchisoni.*	Zone of *M. riccartonensis.*	Zone of *C. symmetricus.*	Zone of *C. Linnarssoni.*	Zone of *C. rigidus.*	Zone of *C. Lundgreni.*	Lower Ludlow.
Cyrtograptus Murchisoni, Carr.	C	R					
C. symmetricus, sp. nov.	...	...	C				
C. Linnarssoni, Lapw.	...	...	...	C			
C. rigidus, Tullb.	...	...	...	...	C	R	
C. tubuliferus, Perner	...	...	...	...	...	R	
C. Carruthersi, Lapw. = *Nilssoni* (Barr.)	...	...	...	...	...	C	R?
C. Lundgreni, Tullb.	...	...	...	...	...	C	
Monograptus basilicus, Lapw.	c	c	c	c	c	c	
M. capillaceus, Tullb.	...	C					
M. dubius (Suess)	...	r	C	C	C	C	c
M. Flemingii (Salt.) var. *α*	...	...	r	c	C	r	
„ „ var. *β*	...	...	...	...	r	R	
„ „ var. *γ*	...	...	...	...	...	C	
„ „ var. *δ*	...	...	...	...	...	C	R?
M. flexilis, sp. nov.	...	...	...	C			
M. Hisingeri, Carr., var.	C	c	c	c	c	c	
M. irfonensis, sp. nov.	...	...	...	...	...	C	
M. Jækeli, Perner	...	...	...	r			
M. priodon (Bronn)	C	c	c	r			
M. riccartonensis, Lapw.	R	C	R				
M. retroflexus, Tullb.	...	...	...	...	C		
M. testis (Barr.) var. *inornatus* nov.	...	...	...	...	...	R	
M. vomerinus (Nich.) var. *α*	C	C	c	c	c	c	
„ „ var. *β*	C	r	r				
M. colonus-like form	...	...	...	...	...	R	C
Retiolites Geinitzianus, Barr.	C						
Retiolites sp.	...	...	...	R			
Stomatograptus sp.	r						

TABLE XII.—DISTRIBUTION OF THE GRAPTOLITES IN THE WENLOCK SHALES IN THEIR ORDER OF APPEARANCE.

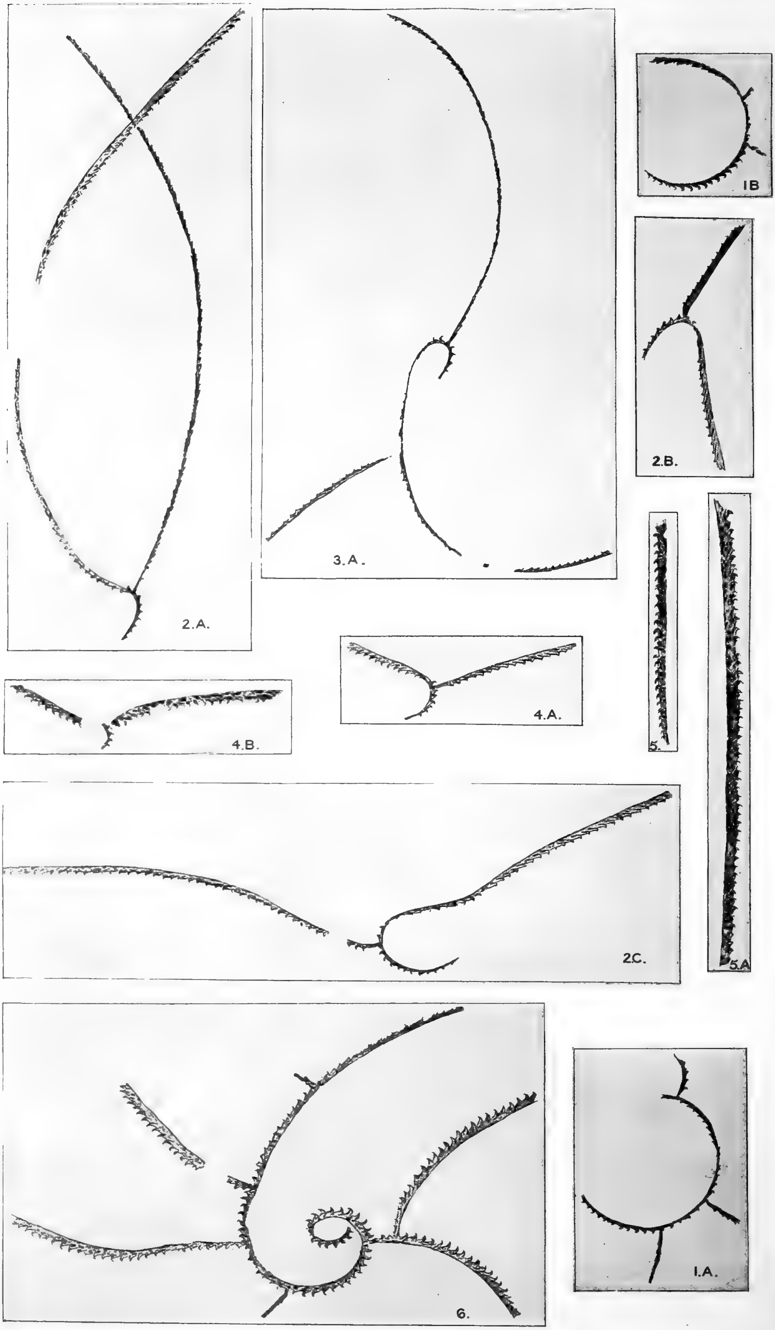
Names of Species. [C = very common; c = common; r = somewhat rare; R = very rare.]	Zone of *C. Murchisoni.*	Zone of *M. riccartonensis.*	Zone of *C. symmetricus.*	Zone of *C. Linnarssoni.*	Zone of *C. rigidus.*	Zone of *C. Lundgreni.*	Lower Ludlow.
Monograptus priodon (Bronn) ...	C	c	c	r			
Retiolites Geinitzianus, Barr. ...	C						
Cyrtograptus Murchisoni, Carr. .	C						
" " var. *crassiusculus*, Tullb.	c						
M. vomerinus (Nich.) var. *α* ...	C	C	C	C	C	C	
" " var. *β* ...	C	r	r				
Stomatograptus sp.	r						
Monograptus basilicus, Lapw. .	c	c	c	c	c	c	
M. Hisingeri, Carr., var.	C	c	c	c	c	c	
M. riccartonensis, Lapw.	R	C	R				
M. capillaceus, Tullb.	...	C					
Cyrtograptus flaccidus, Tullb. ...	...	C					
Monograptus dubius (Suess)......	...	r	C	C	C	C	C
Cyrtograptus symmetricus, sp. n.	...	...	C				
C. Linnarssoni, Lapw.	...	...	...	C			
Monograptus Jækeli, Perner ...	...	...	...	r			
M. flexilis, sp. nov.	...	...	...	C			
Retiolites sp.	...	...	...	R			
Cyrtograptus rigidus, Tullb. ...	...	...	...	...	C	R	
Monograptus retroflexus, Tullb.	...	...	...	...	C		
M. Flemingii (Salt.) var. *α*	...	...	r	c	C	r	
" " var. *β*	...	...	...	...	r	R	
" " var. *γ*	...	...	...	...	...	C	
" " var. *δ*	...	...	...	...	...	C	R
Cyrtograptus Lundgreni, Tullb.	...	...	...	...	...	C	
Monograptus irfonensis, sp. nov.	...	...	...	...	...	C	
M. testis (Barr.) var. *inornatus* nov.	...	...	...	...	...	R	
Cyrtograptus tubuliferus, Perner	...	...	...	...	...	R	
C. Carruthersi, Lapw.	...	...	...	...	...	C	
Monograptus-colonus type	...	...	...	...	...	R	C

In conclusion I wish to express my gratitude to all who have helped me in my work.

I especially wish to thank Prof. Watts for his valuable advice as regards the working of the north of the Long Mountain, and for the loan of specimens collected by himself in that locality; and Mr. Lake for kindly directing me to the most promising sections in the Llangollen Basin.

I should like also to thank Prof. Hughes for allowing me to make free use of the collections in the Woodwardian Museum; and Prof. Lapworth and Mr. Marr for the kind interest and help which they have given me at all times.

Last, but not least, my thanks are due to my friend and colleague Miss E. M. R. Wood, in whose company many sections at the junction of the Wenlocks with the Ludlows were worked, and to



E. M. R. WOOD *del.*

WENLOCK ZONE-GRAPTOLITES, FROM THE WELSH BORDERLAND.

whom I am indebted for the drawings of the graptolites figured in the plate attached to this paper.

EXPLANATION OF PLATE XXIV.

[All the figures are of the natural size.]

Fig. 1 A. *Cyrtograptus Lundgreni*, Tullb. River Irfon. Coll. G. L. Elles.
1 B. *C. Lundgreni*, Tullb. Llwynrhedith Quarry. Coll. G. L. Elles.
Figs. 2 A & 2 C. *Cyrtograptus rigidus*, Tullb. Dulas Brook. Coll. G. L. Elles.
Fig. 2 B. *C. rigidus*, Tullb. River Irfon. Coll. G. L. Elles.
3 A. *Cyrtograptus Linnarssoni*, Lapw. Builth Road. Coll. C. Lapworth. (Type-specimen, re-figured by kind permission of Prof. Lapworth.)
4 A. *Cyrtograptus symmetricus*, sp. nov. Coed Mawr. Coll. G. L. Elles.
4 B. *C. symmetricus*, sp. nov. Near Castle Crab. Coll. G. L. Elles.
Figs. 5 & 5 A. *Monograptus riccartonensis*, Lapw. Walcot. Coll. G. L. Elles.
Fig. 6. *Cyrtograptus Murchisoni*, Carr. Pencerrig. Woodwardian Museum.

Discussion.

Prof. C. Lapworth pointed out the extreme interest of this paper, both from the stratigraphical and from the palæontological point of view. The zonal mapping of the Welsh Silurians commenced by Prof. Watts, carried through the Rhayader Valentian by Mr. Herbert Lapworth, had here been brought out in detail stage by stage through the Wenlocks of the Welsh Border by the Authoress. In a forthcoming paper by Miss Wood, it would be found to be extended to the summit of the Lower Ludlow. The wide-spreading sheets of Silurian strata of similar lithological character, necessarily left unbroken all in one colour by the earlier geological surveyors, would, in the not far distant future, be found banded zone by zone upon our maps in as great detail as the Lias or the Oolites. The excellent map of the Builth district submitted by the Authoress was a type of what these maps will be.

It has long been known that the Silurian was a period of slow and long-continued depression, and subsequent slow upheaval. In these zonal lines on our maps we are now beginning to watch the stages of this general movement and its local interruption by crust-creep. It is most satisfactory to find that the discoveries of the Authoress confirm the views and discoveries of the late Dr. Tullberg, and show (with one exception) that his arrangement of the Scandinavian zones holds good also for the British Wenlock deposits.

With regard to the palæontological bearings of the paper, it touched upon the fringe of a difficult subject, of which, notwithstanding the publication of the suggestive papers of Prof. Nicholson and Mr. Marr and the Authoress, we as yet know but little. The classification of fossil-remains by form, and the classification by presumed descent, have yet to be harmonized. The eidographic grouping, or classification by form, and the phylogenetic grouping, or classification by descent, have both their uses. It has long been known that graptolites, as well as other organisms, were

subject to common 'fashions' at similar geological time-periods, and these fashions are of great value as chronological indices. But the subject is one upon which our knowledge is as yet insufficient to enable us to dogmatize, and the present paper supplies us with several new facts and ideas, which will all be of value in guiding us on the road to correct conclusions.

Prof. WATTS referred to the fact that several years ago he had succeeded in demonstrating that the Lower Wenlock Beds were absent from the Long Mountain district. He was unfortunately unable to continue his work in the district, but he congratulated the Authoress on the marked success which had attended her detailed work in the Silurian strata of the Welsh Border.

24. *The* LOWER LUDLOW FORMATION *and its* GRAPTOLITE-FAUNA.

By Miss ETHEL M. R. WOOD. (Communicated by Prof. C. LAPWORTH, LL.D., F.R.S., F.G.S. Read March 21st, 1900.)

[PLATES XXV & XXVI.]

CONTENTS.

I. INTRODUCTION.

THE Lower Ludlow Shales, which form the lowest section of the Ludlow division of the Silurian System, are most typically developed in the neighbourhood of the picturesque old town of Ludlow. It was in this district that they were first defined and described by Murchison. Lithologically, they are here essentially an argillaceous group of strata, the lower and upper limits of which are well marked by two distinct calcareous beds—the Wenlock Limestone below and the Aymestry Limestone above. Palæontologically, the Lower Ludlow Shales are rich in fossils: brachiopods, cephalopods, crustacea, and graptolites.

When the Lower Ludlow Beds are followed from the Ludlow district north-eastward along their line of strike as far as the valley of the Severn, south-westward as far as Aymestry, and eastward as far as the Malverns and Mayhill, they are seen to retain their lithological characters unaltered, and the Wenlock and Aymestry Limestones are both well developed. But when these beds are traced from the typical area to the west and north-west, the limiting calcareous strata dwindle away and eventually disappear, until, finally, the Lower Ludlow Shales merge lithologically on the one hand into the Wenlock Shales below, and on the other into the Upper Ludlow Flags above. It is clearly impossible, therefore, in these westerly districts to separate, on purely lithological grounds, the Lower Ludlow Beds as a distinct group from the formations which overlie and underlie them.

The proofs that the Lower Ludlow Beds of Britain contain a characteristic graptolite-fauna have been gradually accumulated by the researches of Hopkinson, Lapworth, Watts, Marr, and Lake (see pp. 418–19); and the evidences of the existence of a similar

fauna at a corresponding horizon in Europe have long been known from the discoveries of Continental geologists. But little or nothing has hitherto been worked out with respect to the vertical range of the individual graptolite-species within the limits of the formation itself, or with regard to their geographical distribution in the equivalent strata of Wales and the West of England.

During the last few years I have devoted much of my leisure-time to the study of the graptolitic fauna, the rock-sequence, and the vertical distribution of the various graptolite-species in the recognizable subdivisions of the Lower Ludlow Shales of the typical Ludlow district and of their equivalents along the Welsh Border, in order to ascertain (1) what are the truly characteristic graptolites of Lower Ludlow age as distinct from those of the Wenlock formation, and (2) to what extent the Lower Ludlow Beds are capable of subdivision into graptolite-zones. My results and conclusions are embodied in the present paper.

It is now generally acknowledged that graptolites are among the most reliable fossils for purposes of correlation in the Lower Palæozoic rocks. And the graptolite-fauna of the Lower Ludlow Shales is of more than ordinary interest, for it is the last distinct assemblage of these fossils presented to us before the extinction of the group. Notwithstanding the interest of this particular assemblage of graptolites, it has hitherto received but little attention in Britain. The reason for this neglect is evident. Most of the species of graptolites hitherto recorded from the British Lower Ludlow Beds belonged to forms originally described by Barrande in his famous work on the 'Graptolites de Bohême,' as early as the year 1850; but in some cases he included more than one species under a single specific name, and consequently correct identifications of the British forms were impossible until a thorough revision of Barrande's Bohemian type-specimens had been made. This revision has now been carried out by Dr. Jaroslav Perner ('Études sur les Graptolites de Bohême' pt. iii), and through his kindness I have also been enabled to examine Barrande's type-specimens for myself on the occasion of a recent visit to Bohemia.

Much of the present paper is necessarily palæontological, and consists of descriptions and figures of the more important species of Lower Ludlow graptolites. I have endeavoured to limit the number of species and varieties as much as possible, and have restricted myself mainly to the description of such forms as are of greatest value for stratigraphical purposes.

In working out the stratigraphy of the Lower Ludlow I have studied three districts in some detail, namely:—

(1) The Ludlow District, where the defining limits of the formation are well marked by calcareous beds of considerable thickness;

(2) The Builth District, where the calcareous limiting-beds are still faintly indicated, but the lithological boundaries are more or less indefinite;

(3) The Long Mountain District, where the calcareous limits are absent, and no definite lithological boundaries exist.

I have also collected or examined graptolites from other areas of Ludlow rocks in Britain in addition to these three main districts, as for example from the Dee Valley, the Lake District, Dudley, Abberley, etc. In the present paper I propose first to deal with the succession, lithology, and graptolitic fauna of each of the three main districts; and afterwards to deal briefly with the supplementary districts, and show to what extent the results arrived at accord with those worked out in the more typical areas. The last part of the paper is devoted to the description of the Lower Ludlow graptolites themselves.

II. Literature.

In reviewing the history of stratigraphical research I confine myself as much as possible to that in Great Britain, but when considering the purely palæontological literature on the graptolites of the Lower Ludlow Beds I briefly summarize some of the more important results arrived at abroad.

(1) Stratigraphical.

In the year 1839 Murchison first described and defined these beds in the typical area of Ludlow. In his 'Silurian System' he showed that 'they constitute a great argillaceous mass .... of mudstone .... more argillaceous, less sandy and calcareous' (pp. 204–207) than the Upper Ludlow rocks. He pointed out that they are rich in fossil organisms, and are limited both at their base and summit by well-marked calcareous beds. He also noted the presence of these rocks in other areas along the Welsh Border, as in the undulating country between the Vale of Radnor and the Wye, and in the Long Mountain, etc. He gave a complete section through the Wenlock and Ludlow Beds in the neighbourhood of Builth, noting especially 'the thin band of impure limestone' (*op. cit.* p. 315), made up almost exclusively of the small *Terebratula navicula*, which he believed to be the representative of the Aymestry Limestone.

In 1846 appeared the first volume of the Memoirs of H.M. Geological Survey.[1] In this the Survey officers, referring to the Lower Ludlow rocks of the Builth district, grouped the beds in descending order as follows:—

'(*a*) Argillo-arenaceous rocks, with much oblique bedding and other evidence of irregular accumulation. Many of the beds are arranged in large irregular concretions. 210 feet.
(*b*) Thin limestone-beds. 10 feet.
(*c*) Same rocks as at (*a*). 300 feet.'

These Lower Ludlow Beds are described as being limited at their base by nodules and interrupted beds of limestone (Wenlock Limestone), and at their summit by a thin and interrupted band of limestone composed of little else than the remains of *Pentamerus Knightii* (Aymestry Limestone).

[1] Mem. Geol. Surv. vol. i: 'Formation of the Rocks of S. Wales & S.W. England' p. 23.

In 1880 Prof. Lapworth, in his brilliant paper on the 'Geological Distribution of the Rhabdophora,'[1] grouped the Lower Ludlow as his 'zone of *Monograptus Nilssoni*' and described it as the 'highest and most important graptolitic zone of the Wenlock-Ludlow formation.' He noted that its collective fauna is 'specifically very distinct from that of the Wenlock Shales,' and suggested that the formation 'will probably in the future be found divisible into several distinct zones.'

In 1883 Tullberg,[2] in the great work embodying his researches on the graptolites and graptolite-bearing rocks of Scania, recognized the *Cardiola*-Skiffer as his highest graptolitic zone and correlated them with the Lower Ludlow Beds of Britain.

In 1885 Prof. Watts[3] recorded the occurrence of graptolites of a Lower Ludlow type in the strata of the Long Mountain. Five years later[4] he gave a broad zonal subdivision of these beds by means of their graptolites. His paper marks an important advance in our knowledge of the Lower Ludlow Beds in general, since he recognized two lithological horizons above the Wenlock Shales, each characterized by some distinctive graptolites, namely:—

(2) An Upper Group of hard thick flags with occasional shales, yielding *Monograptus leintwardinensis*, *M. Salweyi*, and *M. Rœmeri*.
(1) A Lower Group of thin muddy shales with rare flaggy ribs, containing *M. colonus*, *M. Nilssoni*, and *Cardiola interrupta*.

In 1892 Mr. Marr[5] published the results of his investigations on the Ludlow rocks of the Lake District. In this paper, as in that on the Stockdale Shales, he utilized graptolites as his characteristic zonal fossils. As this is the most important piece of research hitherto attempted in the zonal division of rocks comparable with the Lower Ludlow Beds, it may be as well to tabulate here his succession in descending order:—

(5) Bannisdale Slates = zone of *Monograptus leintwardinensis* and containing *M. colonus* and *M. Salweyi*.
(4) Coniston Grits = zone of *M. bohemicus* (upper part) with two interesting fossil horizons:—
    (2) Sheerbate Flags with *M. colonus*, *M. bohemicus*, and *M. Rœmeri*.
    (1) Winder Grit.
(3) Upper Coldwell Beds = zone of *M. bohemicus* (lower part) with *M. colonus*, *M. Rœmeri*, and *M. bohemicus*.
(2) Middle Coldwell Beds = zone of *Phacops obtusicaudatus*.
(1) Lower Coldwell Beds = zone of *Monograptus Nilssoni*.

He considered that the Wharfe Grits represent the Lower or Middle Coldwell Beds or both, and that the Moughton Whetstones occurring below them and containing *M. dubius*, *M. Nilssoni*, and *M. uncinatus?* belong probably to the Lower Coldwell horizon.

In the same year Dr. Barrois published his memoir on the 'Distribution des Graptolites en France.'[6] He recorded many species, now

[1] Ann. & Mag. Nat. Hist. ser. 5, vol. vi, p. 201.
[2] 'Skånes Graptoliter' pt. ii, Sver. Geol. Undersökn. ser. C, no. 55.
[3] Quart. Journ. Geol. Soc. vol. xli, p. 532.
[4] Brit. Assoc. Rep. 1890 (Leeds) p. 817.
[5] Geol. Mag. pp. 536 *et seqq.*
[6] Ann. Soc. Géol. Nord, vol. xx, p. 75.

known to be of Lower Ludlow age, from beds in Languedoc, the Pyrenees, the Ardennes, and Normandy. Of several of the species he gave descriptions, but no figures.

In 1895 Lake,[1] in his paper on the 'Denbighshire Series of South Denbighshire,' referred three of his local groups to the period of time intervening between the Wenlock and Aymestry Limestones, and he recognized two distinct graptolitic horizons. His divisions are as follows, in descending order:—

(3) '*Leintwardinensis*-beds.'
(2) Upper gritty beds, unfossiliferous.
(1) Nantglyn Flags, containing *M. Nilssoni* and *M. colonus*.

(2) Palæontological. (Graptolites.)

In 1839 Murchison[2] noted one species of graptolite as being very characteristic of the Upper Silurian strata, and abundant in the Lower Ludlow Beds. This he figured as *Graptolithus ludensis*, but gave no description of it.

In 1850 Barrande, in the 'Graptolites de Bohême,' described and figured five new species now known to be confined to beds of Lower Ludlow age, namely *Monograptus colonus*, *M. Rœmeri*, *M. Nilssoni*, *M. bohemicus*, and *M. chimæra*. Barrande's memoir gave a great impetus to graptolitic research abroad, and during the next thirty years or so various authorities described and figured graptolites from corresponding beds in Central Europe, as, for example, Suess,[3] Geinitz,[4] Heidenhain,[5] Haupt,[6] Kayser,[7] etc.

In 1855 M'Coy, in his 'British Palæozoic Fossils,' pp. 4–5, described what he believed to be Murchison's species *ludensis*, together with a new form (variety) of this which he named *Graptolites minor*.

In 1868 Nicholson, in his paper 'On the Graptolites of the Coniston Flags,'[8] recorded three of Barrande's species from the Lake District, namely, *M. Nilssoni*, *M. colonus*, and *M. bohemicus*, and figured and described each of them. He also figured a specimen of *M. colonus* from the Lower Ludlow Shales of Ludlow.

In 1873 Mr. Hopkinson,[9] who had collected and studied the graptolites from the Lower Ludlow Shales in the typical Ludlow district, recorded several species of Rhabdophora from these beds, but his new species remained undescribed for some years.

In 1880 Prof. Lapworth[10] described and figured five species of graptolites from the Lower Ludlow Shales of the typical Ludlow

[1] Quart. Journ. Geol. Soc. vol. li, p. 22.
[2] 'Silurian System' pl. xxvi, fig. 2.
[3] 'Ueber Böhmische Graptolithen' Haidinger's Abhandl. vol. iv (1851) pt. iv, p. 87.
[4] 'Die Graptolithen ... der Grauwackenformation in Sachsen' 1852.
[5] Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxi (1869) p. 143.
[6] 'Die Fauna des Graptolithengesteines' Neues Lausitz. Mag. vol. liv (1876).
[7] 'Die Fauna der ältesten Devon-Ablagerungen des Harzes' Abhandl. geol. Specialkarte v. Preussen, vol. ii (1878) pt. iv.
[8] Quart. Journ. Geol. Soc. vol. xxiv, pl. xx, figs. 9–11, 18–19 & 22–24.
[9] Brit. Assoc. Rep. (Bradford) p. 83.
[10] Ann. & Mag. Nat. Hist. ser. 5, vol. v, p. 149.

district. Three of these were species previously noted and named by Mr. Hopkinson in manuscript, namely *M. leintwardinensis*, *M. Salweyi*, and *M. serra*, and two belonged to forms which were referred to *M. colonus* and *M. Rœmeri*.

In his paper on the 'Geological Distribution of the Rhabdophora,' published about the same time, Prof. Lapworth recorded *M. scanicus*, Tullb. from the English Lower Ludlow Beds; and paralleled for the first time with the Lower Ludlow of Britain the beds E*e* 2 of Bohemia, containing *M. bohemicus*, *M. chimæra*, *M. colonus*, *M. Rœmeri*, and *M. priodon*; and also the *M. colonus*-zone of Scania with *M. bohemicus*, *M. colonus*, *M. Nilssoni*, and *M. scanicus*.

In 1883 Tullberg,[1] besides completing the stratigraphical work mentioned on p. 418, thoroughly revised the species of graptolites found in the *Cardiola*-Skiffer of Scania. He figured and described the species which had been previously recorded from these beds, and also two new forms, *M. scanicus* and *M. uncinatus*.

In 1884 J. D. La Touche, in his 'Handbook of the Geology of Shropshire,' figured and described several species of graptolites from the Lower Ludlow Beds of Ludlow. Among these were three of Mr. Hopkinson's species, *M. clavicula*, *M. capula*, and *M. retusus*, previously named only in manuscript.

In 1889 Jækel[2] cited several graptolite-species from the 'Graptolithengestein' (Drift) of Northern Germany. From his list it is clear that the fauna of these beds is mainly of Lower Ludlow age. Two new species, *M. frequens* and *M. micropoma*, together with other forms, were described and figured.

In 1897 appeared Prof. Frech's monograph on the graptolites.[3] In this work he figured and described most of the species of graptolites previously recorded from beds of Lower Ludlow age.

The latest addition to our knowledge of the Lower Ludlow graptolite-fauna was made in 1899 by Dr. Perner,[4] who figured and described all Barrande's type-specimens, and thus helped to remove many of the difficulties which previously hindered correct identifications of the English forms with the Bohemian species. Several new species and varieties are recorded by him from the upper beds of Étage E*e* 1 and E*e* 2, the collective fauna of which corresponds remarkably with that of the Lower Ludlow Beds of Britain.

III. General Stratigraphy of the Lower Ludlow Formation.

Before describing the several districts which I have examined in detail, I may here state briefly the main stratigraphical problems offered by a study of the Lower Ludlow Group. Two of these problems are of special importance, namely :—

(1) The determination of the stratigraphical lower and upper limits of the Lower Ludlow Group; and
(2) The natural zonal divisions of the group.

[1] 'Skånes Graptoliter' pt. ii, Sver. Geol. Undersökn. ser. C, no. 55.
[2] 'Ueber das Alter des sog. Graptolithengesteins' Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xli, p. 653.
[3] 'Lethæa Geognostica' vol. ii, pts. ii–iii.
[4] 'Etudes sur les Graptolites de Bohême' pt. iii.

(1) The Lower and Upper Limits of the Lower Ludlow Formation.

The Silurian system of Murchison in the typical area of Shropshire and Herefordshire consists mainly of a great thickness of mudstones, of which the Wenlock Shales and Lower Ludlow Shales form part. Murchison drew the line of division between the Wenlock and Ludlow formations at the Wenlock Limestone, but admitted that the 'Lower Ludlow was simply an upward prolongation of the Wenlock Shale,' and that in some districts 'it was impracticable to endeavour to separate them.' Prof. Lapworth suggested that [1] such a division was made probably 'less from a palæontological than from an æsthetic point of view, and mainly for the sake of physical symmetry'; and urged that the Lower Ludlow was best united with the Wenlock to form the middle division (Salopian) of the Silurian system, the natural horizon of demarcation above it running 'generally along the line of the Aymestry Limestone.'

My study of the graptolitic fauna of the Lower Ludlow rocks entirely bears out the views of both these authorities. In those areas where there is a lithological transition between the Wenlock and Ludlow Beds there is also a palæontological transition, and the one group passes gradually into the other.

The Lower Ludlow graptolite-fauna, although having distinctive characters of its own, yet possesses many marked affinities with that of the Wenlock Shales; and, as I shall point out in the second part of this paper, most of the groups of graptolites characteristic of the Wenlock Beds find their representatives in the Ludlow.

Considered as a whole, however, the graptolite-fauna of the Lower Ludlow is sufficiently distinct from that of the Wenlock to admit of the two formations being separated one from the other, and such a palæontological line of division is of considerable stratigraphical and practical value. In ascertaining the most natural horizon for this zonal line, I have worked in company with my friend Miss G. L. Elles, and the following is the generalized result of our joint observations:—The Wenlock Shales are everywhere characterized by the presence of *Cyrtograptus* and by the *Flemingii*-type of *Monograptus*. In the Lower Ludlow Shales neither of these occurs, but instead the *colonus*- and spinose forms of *Monograptus*, such as *M. chimæra*, are abundant. This may be more readily shown in the following tabular comparison:—

Wenlock Beds.	Lower Ludlow Beds.
Presence of *Cyrtograptus*.	Absence of *Cyrtograptus*.
Presence of the *Flemingii*-type of *Monograptus*.	Absence of the *Flemingii*-type of *Monograptus*.
Absence of the *colonus*-type of *Monograptus*.	Presence of the *colonus*-type of *Monograptus*.
Absence of spinose forms of *Monograptus*, such as *M. chimæra*, etc.	Presence of the spinose forms of *Monograptus*, such as *M. chimæra*, etc.

[1] 'Geological Distribution of the Rhabdophora,' Ann. & Mag. Nat. Hist. ser. 5, vol. v (1880) p. 48.

It will be seen, therefore, that the typical Lower Ludlow fauna is distinct from that of the typical Wenlock, yet so imperceptibly does the one merge into the other that it is difficult to fix the exact horizon of separation. At the horizon of the *Monograptus-Nilssoni* zone one is undoubtedly in Ludlow ground, and the horizon of the *Cyrtograptus-Lundgreni* zone is as certainly Wenlock. Between these horizons intervenes the zone of *M. vulgaris*, sp. nov.; this, where well developed, consists of very thick, hard, calcareous, flaggy shales, and generally makes a feature in the landscape. The palæontological character of this zone allies it more closely with the Ludlow than with the Wenlock, and therefore we have regarded the base of the *M.-vulgaris* zone as the dividing-line between the Wenlock and the Ludlow formations.

The determination of the upper boundary of the Lower Ludlow is also a matter of some difficulty. No graptolites have been found hitherto in the Upper Ludlow Beds of Britain. The majority of the species die out in the Lower Ludlow Shales, but one species characteristic of the highest zone of these beds, namely, *M. leintwardinensis*, Hopk. certainly ranges up into the Aymestry Limestone. So far, then, as the graptolitic evidence goes, the limit between the Lower and Upper Ludlow Beds must be drawn at the top of the Aymestry Limestone, for obviously it would be unadvisable to draw the boundary in the middle of a graptolitic zone. In those areas where the Aymestry Limestone is well developed, as in the Ludlow district, or even where it is but slightly represented, as in the Builth district, there is little difficulty in fixing this upper boundary more or less exactly. But in those areas, such as the Long Mountain, where there is no calcareous representative of the Aymestry Limestone, it becomes practically impossible to draw the line between the Lower and Upper Ludlow on graptolitic evidence alone, the graptolites dying out so gradually that one is unable to determine where they cease altogether. In such cases the lithological characters of the rocks must to a large extent supplement, or indeed entirely replace, the palæontological evidence.

(2) The Zonal Divisions of the Lower Ludlow.

The limited vertical range of the individual species of graptolites in general, together with their wide distribution in space, make them peculiarly suited for zonal fossils; and most of the Lower Palæozoic rocks which contain graptolites, up to and including the Wenlock Shale, have already been variously divided into zones, each of which has a distinctive name. These zones have been found to follow each other invariably in the same order both in Britain and in Western Europe, and it was inferred long since by graptolithologists, such as Mr. Hopkinson and Prof. Lapworth, that detailed work on the graptolites of the Lower Ludlow Shales would demonstrate a corresponding zonal distribution of the species in these beds.

In those districts which I have studied in detail, I have found

that the Lower Ludlow Beds are capable of being grouped into at least four graptolitic zones, but these are apparently less persistent geographically than are the zones worked out in other Silurian formations. Indeed, speaking generally, the Lower Ludlow graptolites (with some notable exceptions which are of well nigh world-wide distribution) have for the most part an extended vertical range and a limited geographical distribution. When, however, we consider the rapid rate of accumulation of the Lower Ludlow strata as compared with that of the Birkhill Shales, for example; and when we remember that the graptolites as a family were dying out at this period, the somewhat imperfect nature of the zonal divisions of the Lower Ludlow Beds is hardly a matter for surprise. Again, owing to the fact that graptolites are of extremely rare occurrence (in Britain) in limestones, and indeed in some cases for a certain distance both above and below them, the graptolitic succession is naturally more incomplete in those areas where the more calcareous development of the Lower Ludlow exists than it is where the purely argillaceous mudstone-facies occurs.

If we consider the evidence derived from all the districts examined, it may be said that the Lower Ludlow Beds (including the Aymestry Limestone) are, broadly speaking, divisible into five main zones, as follows:—

(5) Zone of *Monograptus leintwardinensis*, Hopk.
(4) „ *M. tumescens*, sp. nov.
(3) „ *M. scanicus*, Tullb.
(2) „ *M. Nilssoni* (Barr.).
(1) „ *M. vulgaris*, sp. nov. (at the base).

These zones are not all equally well developed, or even present in every area, but their limitations will be considered when each district is described in detail.

IV. Description of Typical Districts.

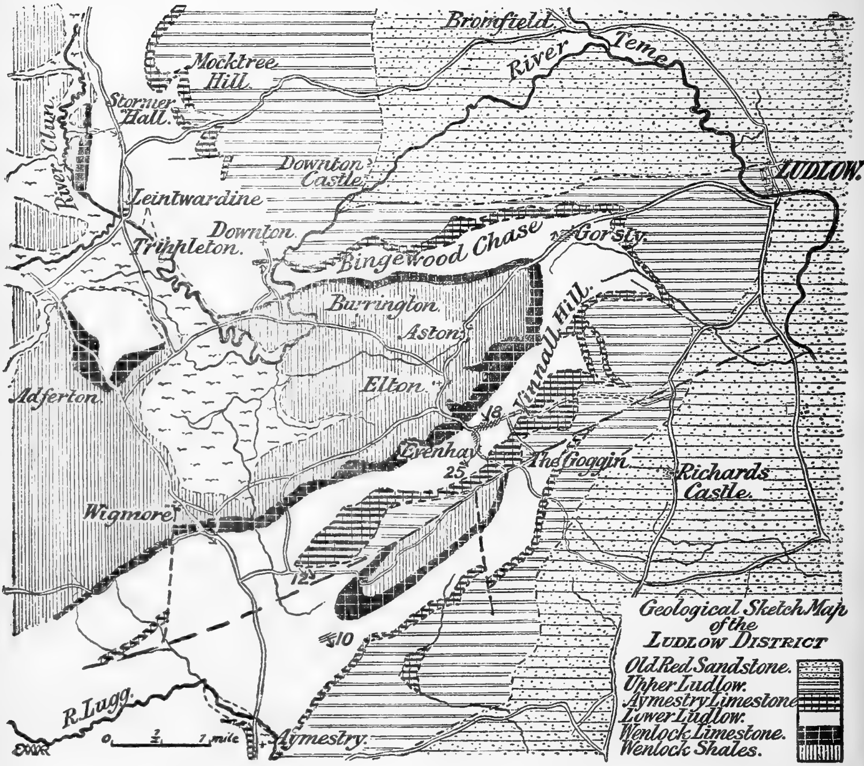
(A) The Ludlow District.

(1) Physical Features and Structure.

The typical district of Ludlow is so well known to geologists that only a very brief notice of its structure and physical features will be necessary. All along the Welsh Borderland the various beds of the Wenlock and Ludlow formations strike in a general north-north-easterly and south-south-westerly direction; but near Downton, some 5 or 6 miles west of Ludlow, the direction of strike changes abruptly to almost due west and east, owing to the fact that the beds are folded into an anticline, the axis of which runs north-east and south-west. On the Upper Ludlow Beds at the extreme north-eastern end of this anticlinal fold is situated the town of Ludlow.

The Wenlock and Ludlow formations are each composed of a calcareous and of a shaly group, and to the alternating occurrence of beds with such different powers of resistance to the agents of denudation are owing the striking scenic features of the district.

Fig. 1.



The Aymestry Limestone forms, generally speaking, the highest ground in the neighbourhood, and gives rise to the ranges of well-wooded hills, with bold and rolling outlines, such as Bingewood Chase, Mocktree Hill, the Vinnalls, etc. The Wenlock Limestone forms a much lower and less conspicuous ridge, while the intervening steep scarp-face is occupied by the Lower Ludlow Shales. The Wenlock Shales which form the core of the anticline, and occur in the neighbourhood of Wigmore, Burrington, etc., occupy the lowest ground in the district.

The Lower Ludlow Shales are exposed in numerous sections, but in no case have I found one in which the complete succession from the top of the Wenlock Limestone to the base of the Aymestry Limestone is laid bare.

(2) Description of Sections.

(*a*) Elton-Lane Section (Lane running in a general easterly-and-westerly direction from Elton through Evenhay Plantation to Hanway Common).—This lane affords on the whole the most complete section in the Ludlow District, especially of the Middle Shales, which are here remarkably rich in graptolites. I have therefore made a detailed traverse of it, collecting graptolites from every few yards, and I give here a sketch-map of the locality (fig. 2, p. 426). The beds dip about 30° east of south, at an angle varying from 15° to 18°, and the ground rises steeply in the same direction, so that continuously higher beds are exposed as one ascends the slope.

The Wenlock Limestone at the base is well exposed in two quarries, A and A′ (see map), along the side of the road, west of a small stream which here marks the boundary between the Wenlock Limestone and the Lower Ludlow Shales. Between this stream and the place where the road bifurcates (B, 120 paces), small exposures of shale occur, but these are crowded with fragments of brachiopods, corals, trilobites, etc., to the complete exclusion of graptolites. There are no exposures along the left road for about 145 yards beyond B, so that I have been unable to obtain graptolites from the lowest parts of the Ludlow Shales At the next exposure (C) graptolites are rare, but *M. colonus* var. *compactus* was identified. A few yards higher up (D, 161 paces), however, graptolites occur in abundance, the recognizable species being *M. bohemicus* (Barr.) very common; *M. Nilssoni* (Barr.) very common; *M. scanicus*, Tullb. (rare); *M. uncinatus* var. *micropoma* (Jækel); *M. varians* var. *pumilus* (very common); *M. vulgaris* var. *β (?)*; *M. dubius* (Suess), etc.

At E (249 paces) *M. Nilssoni*, *M. varians* var. *β*, *M. varians* var. *pumilus*, *M. colonus* var. *compactus*, etc. occur. At F (281) the beds become harder and more flaggy, graptolites are less abundant on the whole, occurring rather in bands. *M. scanicus* and *M. chimæra* (Barr.) become the dominant forms, while *M. Nilssoni* appears to die out gradually. At G (341) is a thin bed of shale about 1 inch thick, crowded with *M. varians* var. *pumilus* to the exclusion of other graptolites, while the beds immediately above and below this band are comparatively barren. Just above the point where the 700-foot contour crosses the road (H) occur *M. scanicus*, *M. bohemicus*, *M. varians* var. *pumilus*, *M. tumescens*, sp. nov., and *M. chimæra*. At I (405), where the Evenhay Plantation commences on the right, the graptolites which were so abundant in the lower beds appear to have died out almost entirely, and their places are taken by *M. tumescens*, which occurs here in great abundance. From the commencement of the wood (I) to the end of the lane (L), the strata grow more and more flaggy and individually thicker-bedded. The graptolites decrease in pro portion as the arenaceous matter increases, so that in the highest exposures there are practically none. Throughout the whole of this distance *M. tumescens* is the prevailing species, and its only

Fig. 2.

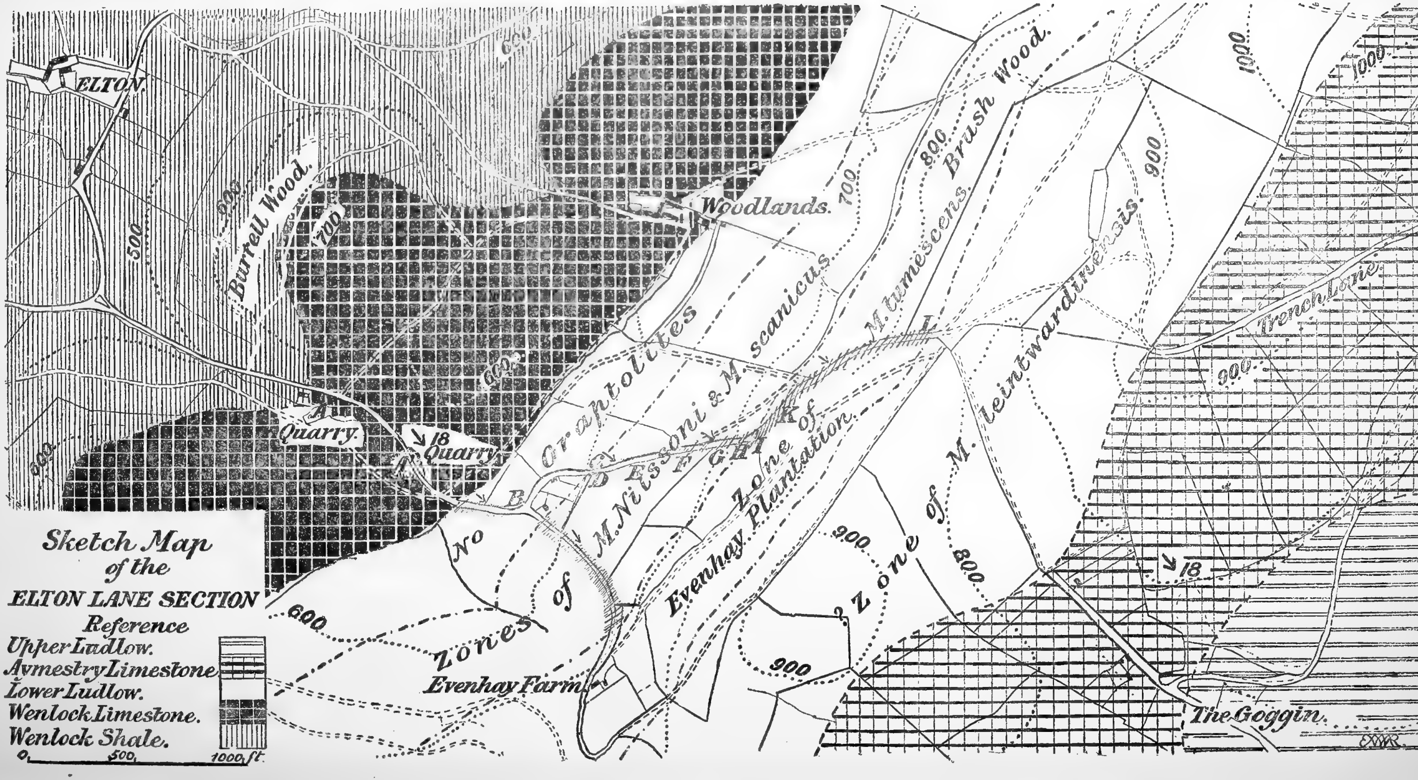

Sketch Map
of the
ELTON LANE SECTION
Reference
Upper Ludlow.
Aymestry Limestone
Lower Ludlow.
Wenlock Limestone.
Wenlock Shale.
0
500
1000 ft.
ELTON.
Burrell Wood.
Woodlands.
Brush Wood.
Quarry.
Quarry.
No Graptolites
Zones of M. Nilssoni & M. scanicus.
M. tumescens.
Zone of Evenhay Plantation.
Zone of M. leintwardinensis.
Trench Lane.
Evenhay Farm.
The Goggin.
500
600
700
800
900
1000

Fig. 3.—*Section from Elton Hall to the Goggin across Elton Lane.*

[Approximate scale: 6 inches = 1 mile.]

U.L. = Upper Ludlow.	*Lt.* = Zone of *M. leintwardinensis.*	*Ni.* = Zone of *M. Nilssoni.*
A.L. = Aymestry Limestone.	*Tm.* = Zone of *M. tumescens.*	*W.L.* = Wenlock Limestone.
	Sc. = Zone of *M. scanicus.*	

associates that I have found are a small fragment of *M. bohemicus* and one of *M. chimæra (?)* which occurred at K (457 paces). Beyond the gate (L) all exposures cease, so that this section affords no opportunity of examining the yet higher beds intervening between this point and the Aymestry Limestone.

In the shales especially, the graptolites are for the most part well preserved, but even there they show evidence of having been somewhat squeezed, and in the upper and flaggier beds of the section they have suffered considerably from the effects of pressure. The accompanying section (fig. 3) from Elton Hall to the Goggin illustrates the general succession of the beds in this part of the district.

(*b*) Elton–Evenhay Farm Section.—A section similar to the foregoing is seen in the lane which branches off from the first road at the foot of the hill and winds past Evenhay Farm. Along this lane also I have collected graptolites from every few yards. Seeing, however, that the general assemblage and sequence of fossils is practically the same as in the former sections, it is unnecessary to describe the section and its fauna in detail. Here the lower richly graptolitiferous beds are especially well seen.

(*c*) Elton–Ludlow Road Section.—The road from Elton to Ludlow cuts through both the Wenlock and Aymestry Limestones, and exposes a fairly good section through the middle part of the Lower Ludlow Shales. Here, as in the Elton Lane section, the beds for some distance above and

below the limestones are not laid bare. The lowest beds seen, which are about one-eighth of the way up in the succession, have yielded *M. bohemicus*, *M. Nilssoni*, *M. scanicus*, *M. chimæra*, *M. dubius*, etc. In a small quarry in the hard flaggy shales near Gorsty Farm, at the top of the hill, *M. tumescens* and *M. tumescens* var. *minor* occur in abundance and to the exclusion of other species. These beds are identical with those in the Elton Lane section between I and L.

(*d*) Leintwardine–Stormer Hall Road Section.—A small but richly fossiliferous exposure of the Lower Ludlow Shales is exhibited along the roadside south of Stormer Hall ('Stanner Hall' of Lapworth, etc.). This locality is of especial interest as being the type-locality for *M. Salweyi*, Hopk. The typical form occurs here in great abundance, but is seldom met with anywhere else in the district. It is associated with *M. dubius*, *M. uncinatus* var. *micropoma*, *M. colonus* var. *compactus*, and *M. varians* var. *a*. The slender curved graptolites, such as *M. scanicus* and *M. Nilssoni*, are conspicuous by their absence, and it is possible that these beds represent a somewhat lower horizon than those seen in the other sections just described, but as there are no other exposures near by it is impossible to speak with certainty.

(*e*) Church Hill Quarry, Leintwardine.—This quarry, now overgrown and practically inaccessible, was made in the hard flags, known as 'Leintwardine Flags,' which occur at the top of the Lower Ludlow Shales immediately below the Aymestry Limestone. It was from this locality that the type-specimens of *M. leintwardinensis*, the highest British graptolite yet known, were obtained. The only other localities in the district where I have found this characteristic species are in the hard flags at the top of Mocktree Hill and at Aymestry. In the large quarry at Aymestry I obtained a few fragments, occurring in calcareous beds crowded with brachiopods, trilobites, etc., which belong undoubtedly to the Aymestry Limestone.[1]

(3) Summary.

Judging from the field-evidence adduced in the foregoing pages, it would appear that the graptolitiferous members of the Lower Ludlow Shales and Aymestry Limestone in the typical area may be grouped into four zones:—

4. Zone of *M. leintwardinensis*	485 feet (including the Aymestry Limestone, 275 feet).
3. „ *M. tumescens*	220 feet.
2. „ *M. scanicus* .... 1. „ *M. Nilssoni* (at the base)...	350 feet (including the 130 feet at the base which have yielded no graptolites) in the Elton-Lane section.

[1] In the Woodwardian Museum, Cambridge, there is a well-preserved specimen of *M. leintwardinensis* occurring in a limestone, labelled 'Upper Ludlow, Brocton & Burton.' Unfortunately the exact horizon is unknown, but it is probably that of the Aymestry Limestone. The graptolite is associated with *Strophomena depressa*, *Chonetes lata*, and *Rhynchonella nucula*.

These zones are not all equally rich in graptolites, for nearly the whole of the abundant graptolitic fauna of the Lower Ludlow occurs in the zones of *Monograptus Nilssoni* and *M. scanicus*, while the two highest zones—those of *M. tumescens* and *M. leintwardinensis* —each contain practically only one species. Again, the two lower zones yield numerous graptolites throughout their whole extent, while in the two upper zones graptolites are for the most part rare, occurring abundantly only in certain bands.

The zones of *M. Nilssoni* and *M. scanicus* are perhaps less clearly defined than the higher zones, and it is a matter of some difficulty to decide which are the best graptolites to select for the zonal forms. The three most characteristic graptolites of these beds are undoubtedly *M. bohemicus*, *M. Nilssoni*, and *M. scanicus*. *M. bohemicus* is very abundant in the lowest beds; owing, however, to the long range of this graptolite, it is not advisable to select it for the zonal form. *M. Nilssoni* and *M. scanicus* occur in association; but, as was well seen in the Elton-Lane section, *M. Nilssoni* is more abundant in the lower beds, and *M. scanicus* more characteristic of the upper. It is convenient, therefore, to group the lower 350 feet of Lower Ludlow Shales, so rich in graptolites, into two zones—a lower zone, that of *M. Nilssoni*, containing *M. bohemicus*, *M. colonus* var. *compactus*, *M. uncinatus* var. *micropoma*, *M. varians*, *M. dubius*, etc.; and an upper zone, that of *M. scanicus*, with *M. Rœmeri* and *M. chimæra* as the characteristic graptolites.

The zones of *M. tumescens* and *M. leintwardinensis* are well marked, both lithologically and palæontologically. *M. leintwardinensis* clearly ranges up into the Aymestry Limestone, above which no graptolites are known, and therefore the Aymestry Limestone should be included in the zone of *M. leintwardinensis*.

(B) The Builth District.

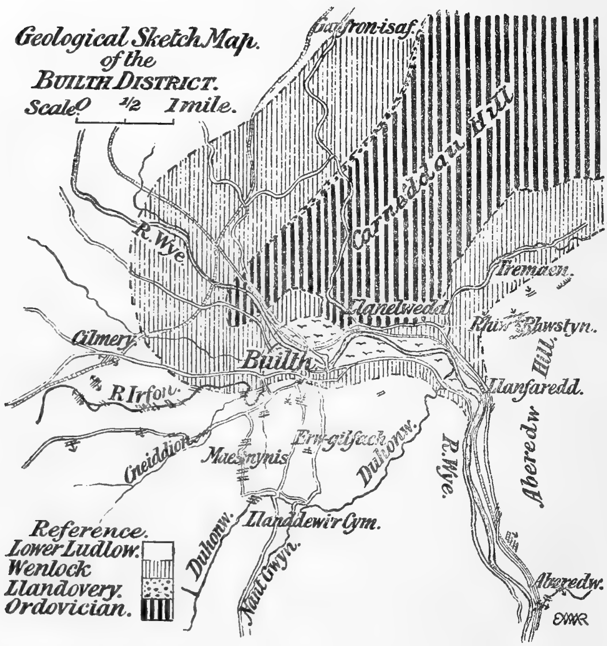
(1) Physical Features and Structure.

The Builth district, as examined by me, includes the range of the Aberedw Hills from Rhiw Rhwstyn on the north to Aberedw on the south, and also the area lying immediately south and south-west of the town of Builth. The Carneddau Hills, which form part of a buried mountain-range composed of Ordovician rocks, rise up as an anticline, the axis of which runs north-east and south-west, and occupies the central part of the area. Resting unconformably upon them is a thin band of Llandovery Grit, and above this come the various zones of the Wenlock Shales. These are folded into a broad syncline on the west of the Carneddau Hills, in the centre of which occur the lowest members of the Ludlow Shales. The Wenlock Shales pass up conformably into the Lower Ludlow without any marked lithological change.

The Lower Ludlow Beds occupy the rising ground between the valley of the Wye and the high hills of Mynydd Eppynt on the south and Aberedw on the east, which attain an elevation of

1400 to 1500 feet. The higher slopes of these are formed of Upper Ludlow strata, capped by Old Red Sandstone, the scenery of which is somewhat bare and desolate. The ground occupied by the Lower Ludlow Beds, on the other hand, is for the most part cultivated or well wooded; though on the steep slopes of the Aberedw Hills the scenic features produced by the Lower and Upper Ludlow rocks are practically indistinguishable.

Fig. 4.



These hills give birth to many small streams which cut their way in deep gorges through the hard flaggy rocks, while in the shaly beds the valleys are more open. Many of the deepest gorges, such as those of the Edw and Duhonw, are richly wooded and form picturesque scenery.

(2) Lithological Characters.

The Lower Ludlow rocks in the Builth district are somewhat varied in their lithological characters, which on the whole differ but little from those of the underlying Wenlock formation. They consist mainly of dark shales, flags, and mudstones, of varying degrees of hardness. The shales are of a dark greyish-brown, occasionally very thin and papery, but for the most part hard and

fairly thick-bedded. The majority of the rocks are of the nature of mudstones or mudstone-flags. The typical mudstones usually weather to a rather light brown, while some of the flaggier and more calcareous beds retain their original dark-grey coloration. These rocks frequently show concretionary structure, some of the con cretions measuring several feet in diameter. Typical flags breaking with a splintery fracture are less common, and are found mainly in the highest beds of the formation. All the rocks contain flakes of mica more or less abundantly. At certain horizons thin bands or nodules of limestone occur in the shales; these generally weather more deeply than the strata with which they are inter bedded, and thus their position may be readily detected in a section.

The rocks are for the most part richly fossiliferous. Graptolites, however, are practically confined to the shales, limestones, and micaceous flags, while the mudstones yield abundant brachiopods, trilobites, corals, etc. Unfortunately all the beds have been subjected to considerable earth-movement, and in consequence the fossils, especially the graptolites, have been deformed.

The local development of the Lower Ludlow rocks in this area is of peculiar interest, for not only do the rocks combine the lithological characters of the Ludlow sub-calcareous facies already described with those of the purely mudstone-facies of the areas farther north to be noticed later, but the graptolitic fauna shows a similar intermediate character. The lower limits of the Lower Ludlow formation can be suggested on palæontological grounds alone, while, on the other hand, the most natural upper boundary may be best fixed by lithological considerations. The Builth district is exceptionally rich in exposures, and therefore sections can be traced right through the formation from base to summit.

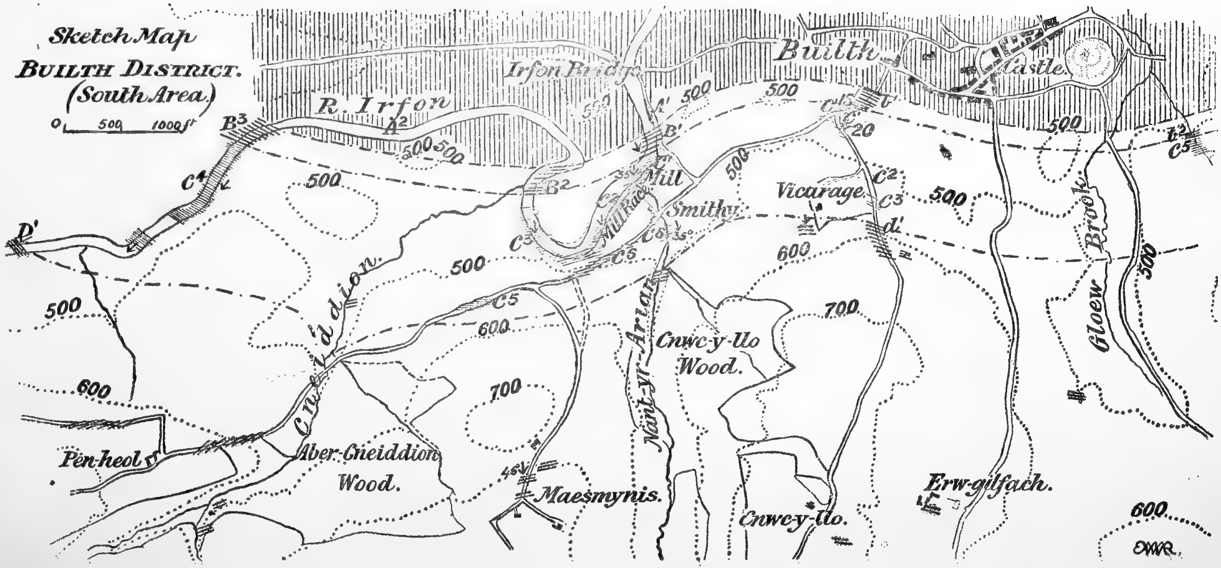
(3) Area lying South of the Wye.

(*a*) River-Irfon Section. (See map, fig. 5, p. 432.)—A complete section is exposed along the banks of the Irfon, from the upper zones of the Wenlock Shales into the Lower Ludlow Shales, and the beds are rich in graptolites throughout.

Starting from Irfon Bridge, the first beds (A^1) which are exposed along the right bank consist of black shales and harder beds with large limestone-nodules, dipping at an angle of about 35°. They have yielded *Monograptus Flemingii* var. δ and *M. dubius*. These must undoubtedly be grouped with the Wenlock Shales, and form the highest zone of that formation.

They are succeeded by a band of dark, thickly-bedded, hard calcareous flags (B^1), breaking with irregular fracture and forming a conspicuous feature, which projects into the stream and narrows its bed considerably. Graptolites are rare in the flags, and even when they do occur they are distorted almost beyond recognition. *M. vulgaris* probably occurs, and from analogy with other exposures

Fig. 5.


Sketch Map
BUILTH DISTRICT.
(South Area.)
0 500 1000 ft
R. Irfon
Irfon Bridge
Builth
Castle
Mill
Mill Race
Smithy
Vicarage
Cneiddion
Nant-yr-Arian
Gloew Brook
Cnwc-y-llo Wood.
Cnwc-y-llo.
Aber-Cneiddion Wood.
Maesmynis.
Erw-gilfach.
Pen-heol
500
600
700

I think that these flags, which are about 100 feet thick, should be regarded as the basement-bed of the Ludlow formation.

Above these again comes a thick series of brownish-grey flaggy shales with thin beds of limestone (C). These are well exposed in the bed of the stream, and at C^1 have yielded *Monograptus colonus* (Barr.), *M. bohemicus*, and *M. Nilssoni*. At the Mill Race (C^2) the shales are especially rich in the same graptolites. The right bank of the river at this point, and for some distance up stream, rises almost precipitously to a height of 60 or 70 feet; and similar beds, containing the same graptolites, occur all up the cliff, so that they must be of considerable thickness, probably about 500 or 600 feet. At C^3 the shales yield *M. colonus* and *Retiolites spinosus*, sp. nov. in great abundance, the surfaces of the rock being almost hidden from sight by the graptolites; the specimens, however, are much squeezed.

Farther up hard flaggy beds (B^2) are again exposed at the curve which the river makes at this spot. Still higher up, the hard concretionary flags of A and B are again seen in the bed of the river (A^2, B^3), and the graptolitiferous shales (C^4) containing *M. colonus, M. Nilssoni, Retiolites spinosus*, etc., forms identical with those seen at C^2 and C^3, are re-entered. They are succeeded by hard flags (D^1) which are much contorted and folded. The dip of the beds varies considerably both in amount and direction in the higher reaches of the river, while their strike bends gradually round until, in the centre of the syncline of Wenlock Shales west of the Carneddau Hills, it runs in a north-north-easterly and south-south-westerly direction. This graptolite-bearing bed is easily recognized in the field, and forms an important zone almost at the base of the Lower Ludlow Shales. I have also recognized it in the country west of Builth, near Glan Irfon, and at Cilmery Station; and Miss Elles has traced it farther north near Gaufron-isaf, etc., but graptolites are rare at the last-named locality.

In the Irfon section two distinct horizons in these Lower Ludlow Beds are, therefore, recognizable:—

(2) Flaggy shales and thin limestones rich in graptolites: *M. colonus, M. bohemicus, M. Nilssoni*, and *Retiolites spinosus*. 500 to 600 feet.
(1) Hard calcareous flags with *M. vulgaris*. 100 feet.

(*b*) Builth-Llanddewi'r Cwm Road-Section.—An excellent section, confirmatory in every way of the foregoing, is seen along the road from Builth past the Vicarage to Llanddewi'r Cwm. At the base come the hard flags (b^1) which have yielded *M. vulgaris* and *M. dubius*; the graptolites, however, are badly preserved, and any identifications must be somewhat doubtful. Owing to their hardness, their outcrop forms a scarp, and thus they are easily mapped: they pass up gradually into the shaly graptolitiferous zone (c). The detailed succession of these beds is particularly well seen for some 40 or 50 yards along the Vicarage road, which here joins the main road (c^1). The beds dip at an angle of 20°, and strike 10° to 20° south of east.

The following is the succession in descending order :—

(5) Light-brown flaggy shales with *Monograptus bohemicus*, *M. Nilssoni*, *M. colonus*, and *Retiolites spinosus* (rare). 4½ feet.
(4) Thin reddish-brown limestone, containing *M. colonus* in abundance and numerous fragments of shells, etc. 3 to 4 inches.
(3) Shales (same as 5) with *M. bohemicus*, *M. Nilssoni*, *M. colonus*, and *Retiolites spinosus* (abundant). 8½ feet.
(2) Thin limestone, made up of fragments of trilobites, brachiopods, crinoid-stems, etc., and containing *M. colonus*. ½ inch.
(1) Alternating dark flaggy and fissile shales containing *M. Nilssoni*, *M. colonus*, and *Retiolites spinosus* in bands. 12 feet.

This section is prolonged without much interruption for 40 or 50 yards; the paler shales predominate, some beds being of the nature of mudstones, others more shaly. The same graptolites occur, but are for the most part fragmentary and rare. There are no more exposures for 150 yards; then at c^2 occur thin, light-brown, papery shales with limestone-nodules, and flaggier beds containing a few badly-preserved graptolites, *M. colonus (?)*, and various mollusca. At c^3 the ground rises steeply, owing to the increasingly flaggy nature of the beds and the decrease of argillaceous material, while the graptolites *(M. colonus, Retiolites ?)* are relatively few, and finally seem to disappear altogether. At *d* the beds are flaggy, yellowish-brown mudstones, breaking with conchoidal fracture: they have yielded no graptolites, and only a few small brachiopods.

The rich graptolite-bearing shales (c^5) with the underlying flags (b^2) are exposed east of Gloew Brook, near the Oaklands, but I have not traced them farther eastward.

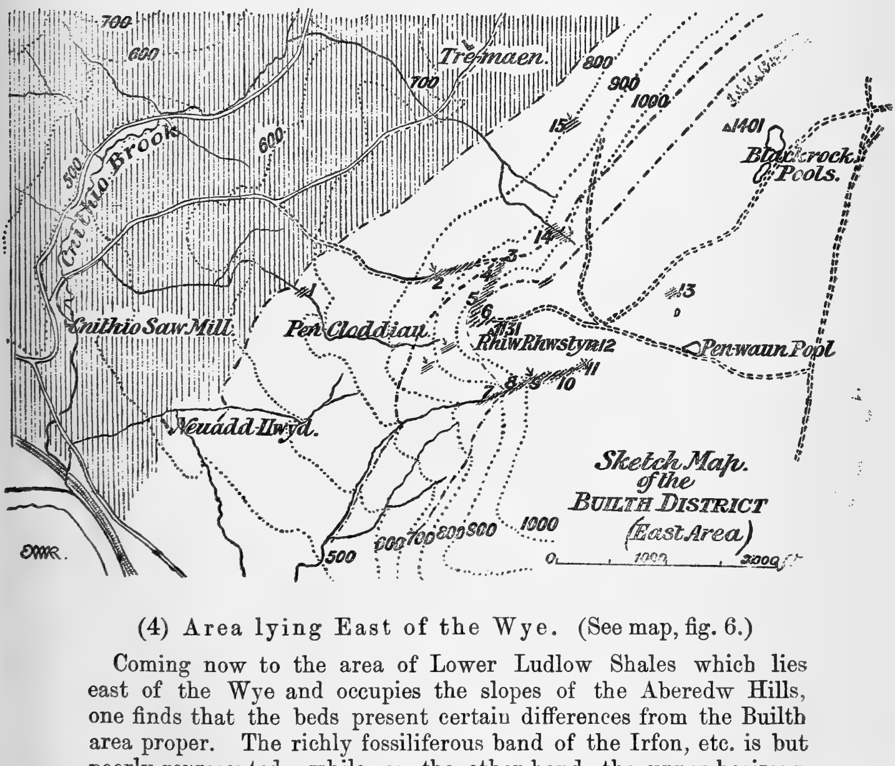
The thin papery shales seen at c^2 and c^3 at the base of the arenaceous series are also exposed in the Maesmynis road, beyond the Smithy, and in the Nant-yr-Arian (c^6), but graptolites are for the most part rare and indifferently preserved, and I have identified only *M. dubius* and *M. colonus*. The succeeding mudstones and flags are seen in various quarries and exposures farther south (see maps, figs. 4 & 5, pp. 430 & 432); but search for graptolites in any of these higher Ludlow Beds in the district south of Builth has so far proved practically fruitless, and therefore it would seem impossible in the meanwhile to fix the upper limit of this formation by means of graptolites. Everywhere the beds are mudstones and calcareous flags, rich in brachiopods, with here and there traces of graptolites showing that they had not altogether died out; thus, in a small quarry along the roadside, about ⅓ mile south of Maesmynis, I found a few fragments which probably may be referred to *M. leintwardinensis*. Still farther south, along the banks of the Duhonw, the rocks are dark micaceous flags with splintery fracture; these higher beds, however, though apparently well adapted for the preservation of graptolites, have, so far, yielded none. Judging from the evidence obtained at Aberedw, which lies to the south-east, I believe that these flags belong to the *M.-leintwardinensis* zone; and as that species occurs only in certain bands among a great thickness of unfossiliferous beds, it is possible that it may yet be found here.

As I have already mentioned, these upper flags and mudstones are rich in brachiopods, especially certain calcareous bands. One bed composed largely of casts of *Dayia navicula* is well seen in a quarry at Erw-gilfach, about 1 mile south of Builth, in association with *Spirifera crispa* and *Scenidium Lewisi* (kindly identified by Mr. F. R. C. Reed). The first-named brachiopod occurs in great abundance in the higher beds of the Lower Ludlow, in the area lying east of the Wye, and does not seem to be confined to any one horizon. I have not traced it for any distance in the south-western area.

(*c*) Summary.—Reviewing the whole of the evidence obtained from this area, the Lower Ludlow formation would seem to be divisible into three groups :—

(3) Mudstones and calcareous flags. Zone of *Monograptus leintwardinensis.*
(2) Shales and thin beds of limestone rich in graptolites. Zone of *Monograptus Nilssoni.* 500 to 600 feet.
(1) Hard flags. Zone of *Monograptus vulgaris.* 100 feet.

Fig. 6.



(4) Area lying East of the Wye. (See map, fig. 6.)

Coming now to the area of Lower Ludlow Shales which lies east of the Wye and occupies the slopes of the Aberedw Hills, one finds that the beds present certain differences from the Builth area proper. The richly fossiliferous band of the Irfon, etc. is but poorly represented ; while, on the other hand, the upper horizons,

which were practically ungraptolitiferous in the district lying south of the Wye, here contain abundant graptolites.

(*a*) Section from Cnithio Brook to Rhiw Rhwstyn.—In the brook at Cnithio Sawmill undoubted Wenlock Shales occur, belonging to the zone of *Cyrtograptus Lundgreni*. From the brook the ground rises somewhat rapidly, the beds becoming increasingly flaggy, but no good exposures are seen for some distance up the hill. In an old quarry (1 in fig. 6, p. 435), however, below Pen-Cloddiau Farm, hard bluish-grey flags occur which contain abundant graptolites, species of *Orthoceras*, and brachiopods. The graptolites belong to the species *Monograptus vulgaris* and *M. dubius*, but they are badly preserved and much distorted, owing to the cleavage that the rocks have undergone. I class these beds unhesitatingly with the Lower Ludlow, but the exact position of the base of this formation cannot be determined with certainty.

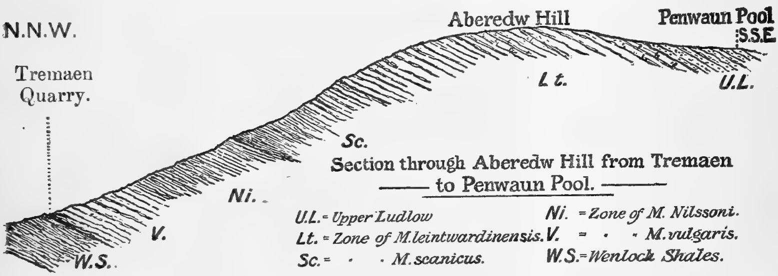
The next exposure is some distance farther up the hill, in a small quarry on the right of the road (2). Here occur two narrow limestone-bands, about 5 or 6 inches thick, separated by 18 inches of shale. The lowest limestone-band has yielded no fossils, but the upper one, which is yellowish-brown and thoroughly rotten, is crowded with *M. colonus* and *Orthoceras*, similar to the rotten limestones seen in the Vicarage road-section. It probably, therefore, represents the zone of *M. Nilssoni*, but this is the only locality where I have detected it, and I have not hitherto found either *M. Nilssoni* or *M. bohemicus* in this eastern area.

As we ascend the section the shales become more micaceous and graptolites are rare, and I have only identified *M. dubius* with certainty. The beds dip 10° east of south at an angle of about 16°. At (3), where the road bends sharply and the slope of the hill increases rapidly, graptolites occur in abundance, and a complete section is seen up to the top of the hill. For the first 75 yards the beds consist of greyish-brown shales which have yielded *M. scanicus* (common), *M. chimæra* (common), *M. dubius*, etc. As the beds become increasingly flaggy, *M. Rœmeri* and *M. bohemicus* appear together with *M. scanicus* and *M. chimæra*. At (5), about 150 yards from the bottom, light-brown, micaceous, flaggy mudstones have almost entirely replaced the shales, and a thin calcareous band, composed largely of the casts of *Dayia navicula*, intervenes. It was apparently at this horizon that the officers of the Geological Survey drew the boundary between the Wenlock and Ludlow formations. Immediately above it come a few feet of a shale which has yielded several specimens of *M. bohemicus*. The occurrence of this graptolite so high up in the Lower Ludlow is of interest, as it bears out the evidence obtained in the Ludlow district of the long range of the species. The shale is followed by a considerable thickness of flaggy mudstones (6) which, however, have yielded no graptolites.

(*b*) Confirmatory Aberedw Hill-Sections.—A section confirmatory of the foregoing is seen in the small stream-course immediately south of Rhiw Rhwstyn. Here only the uppermost

graptolitiferous beds are seen, and at (7) they have yielded *Monograptus scanicus*, *M. chimæra*, *M. Rœmeri*, and *M. dubius*. Above these come hard, dark, calcareous flags, slightly micaceous, and with a concretionary structure (8), which give rise to a waterfall 12 feet high. They are a continuation of the flaggy mudstones (6) above the *M.-bohemicus* shales seen in the road-section, and form a marked feature all along the hill-range. They contain no graptolites and but few fossils of any kind. These flags are succeeded by slightly less flaggy beds, but still destitute of graptolites. Above the 1000-foot contour (9) the stream-course rises more rapidly, and at (10)

Fig. 7.—*(Approximate scale: 6 inches = 1 mile.)*



occurs a band crowded with casts of *Pentamerus Knightii*. This is followed by greyish-brown micaceous flags, splitting readily, which have yielded several specimens of *M. leintwardinensis*. At (11) dark calcareous flags come in, as at (8), barren of fossils, interstratified with calcareous bands crowded with brachiopods (mainly *Dayia navicula*), corals, crinoid-stems, etc. At (12), farther north, are dark calcareous flaggy beds with abundant fossils, and on one slab *Pentamerus Knightii* occurs in association with *Monograptus leintwardinensis*. At (13) light-brown mudstones contain bands almost entirely composed of the casts of *Pentamerus Knightii*, *Dayia navicula*, corals, polyzoa, etc.

It would appear, therefore, from this section that it is impossible to draw any palæontological line between the Lower Ludlow Beds and the representatives of the Aymestry Limestone, for the graptolite (*M. leintwardinensis*) characteristic of the highest zone of the Lower Ludlow occurs in association with brachiopods, such as *Pentamerus Knightii*, which are typical elsewhere of the Aymestry Limestone. Consequently, the evidence obtained in this Aberedw area confirms the conclusion previously arrived at from a study of the corresponding rocks in the typical district of Ludlow, namely, that the Aymestry Limestone should be regarded as part of the Lower Ludlow formation.

Other small exposures are seen at various points along the hill-side. One good section through the lower beds of the *M.-scanicus* zone and the comparatively unfossiliferous shales below is visible in a

small gully (14 in fig. 6, p. 435) north-east of the main road-section. Still farther north-east, in an old quarry south-east of Tremaen Farm (15), dark flaggy mudstones, weathering into minute fragments, yield abundant fossils:—brachiopods, trilobites, cephalopods, etc. It is difficult to say what is the exact horizon of these beds; they may possibly represent the Wenlock Limestone.

In a quarry near Llanfaredd Church, 1 mile south of Rhiw Rhwstyn, hard calcareous flags occur, with limestone-bands and nodules crowded with *Pentamerus* and other brachiopods. This no doubt represents the Wenlock Limestone, and thus marks the base of the Lower Ludlow Beds.

(*c*) Section in the River Edw, Aberedw.—I have not examined the various exposures seen along the hillside south of Llanfaredd, but at Aberedw itself I have found the typical *Monograptus leintwardinensis* in considerable abundance. It occurs, associated with small specimens of *Lingula lata*, in the craggy cliffs of the River Edw. Owing to the steepness of the banks, the beds have slipped down from above in large masses, and it is often difficult to say with certainty whether the beds are *in situ* or not. The beds here too are much folded, and the strike changes every few yards. The graptolites occur at one or two horizons among a considerable thickness of dark micaceous and calcareous unfossiliferous flags. Unfortunately I have been unable here to determine the relations of this zone to the graptolite-zones below, for the beds appear to be, on the whole, barren of fossils.

(*d*) Summary.—The succession, then, of the Lower Ludlow Beds in the area east of the Wye is, in descending order, as follows:—

(4) Hard calcareous flags and mudstones with bands rich in brachiopods: *Pentamerus Knightii*, *Dayia navicula*, etc. Zone of *Monograptus leintwardinensis*. 400 feet?

(3) Light-coloured shales passing up into flaggy mudstones. Zone of *Monograptus scanicus*. 250 feet.

(2) Shales and thin limestone-bands. Zone of *Monograptus Nilssoni* probably. The upper beds are more micaceous and flaggy, and less fossiliferous.

(1) Dark calcareous flags. Zone of *Monograptus vulgaris*.

[(2) and (1) together:] 400 to 450 feet?

The upper limit of the Lower Ludlow Beds has not been determined in this area.

(5) Comparison of the two Areas.

In the eastern part of the Builth district, therefore, one richly graptolitiferous zone occurs, that of *M. scanicus*, which would seem to be unrepresented in the area lying south and south-west of Builth, while at the same time the zone of *M. Nilssoni* is less richly fossiliferous. As regards the comparatively poor development of the *M.-Nilssoni* zone, it may be possibly due to the lack of exposures at the right horizon; but at all events it is certainly not so thick as it is in the Irfon and Vicarage-road sections. There is no doubt, however, that the *M.-scanicus* zone is absent as

such in the southern and south-western parts of the district. The highest zone, that of *Monograptus leintwardinensis*, as developed at Aberedw and at Rhiw Rhwstyn, agrees lithologically with the beds which I have referred to the same zone in the valley of the Duhonw, and would seem to be of considerable thickness.

In attempting to offer an explanation for the variations in the palæontological characters of the rocks in areas so nearly adjacent, it is first of all necessary to consider briefly the conditions favourable to the existence and preservation of graptolites in general. As Prof. Lapworth has maintained, it is probable that the graptolites were not entirely free-swimming animals, but were attached to various floating bodies, such as seaweeds, which would tend to accumulate in dense masses in still waters such as those of the Sargasso Sea. A quiet though not necessarily deep sea, in which slow sedimentation would take place, would appear therefore to be the best condition for the existence of graptolites, while at the same time the fine-grained sediments thus formed would be most favourable for their preservation. It is clear, then, that coarse-grained and rapidly accumulated sediments, pointing as they do to the proximity of land and to the existence of current-swept seas, would be unfavourable both for the occurrence and for the preservation of graptolites. Such conditions seem to have largely prevailed during the deposition of the Ludlow Beds, comparatively fine-bedded argillaceous shales alternating rapidly with coarse-grained arenaceous and calcareous flags and mudstones. The upper beds, especially, of the Lower Ludlow Group were probably formed under more or less continuous shore-conditions, with occasional pauses in the rapid sedimentation. Graptolites are everywhere abundant in the shales, while they are almost entirely absent from the coarser sediments. It is, therefore, possible that while the shales containing *Monograptus scanicus* were being laid down in comparatively quiet waters in the south-eastern area, the more rapidly moving waters of the southern and south-western portions of the district which lay too near the shore-line were unfavourable for the existence of graptolites. The fact that the beds belonging to the *M.-Nilssoni* zone south of Builth are of about the same thickness as the *M.-Nilssoni* and *M.-scanicus* beds combined in the eastern area, seems to lend support to this view. But against it, on the other hand, is the fact that the uppermost horizons of the *M.-Nilssoni* zone near Builth, though graptolitiferous, have yielded no forms of the *M.-scanicus* or *M.-chimæra* type. The thickness, too, of the beds in adjacent areas cannot be relied upon, for the strata in the west, lying as they do nearer the old coast-line, would naturally be thicker than those farther east.

Another explanation suggests itself, but its application in this case could be ascertained only after a detailed mapping of the country. According to Miss Elles, in the Wenlock Shales of this district there has been an overlap of some of the higher zones on to the lower zones, and a glance at the geological map of the area

lying south and south-west of Builth shows that this phenomenon is well marked in the succeeding beds. Each formation in turn overlaps on to the one beneath it, so that at Llangadock the Upper Wenlock (? Lower Ludlow) Beds rest on the Llandovery, the former are overlapped by the Ludlow Beds, which in their turn are almost concealed by the Old Red Sandstone. Still farther south the Wenlock and Ludlow Beds are completely overlapped, and the Old Red Sandstone rests upon the Ordovician rocks. Similar conditions, too, prevailed in the Llandovery period, as Mr. H. Lapworth has clearly shown in the Rhayader district. It would seem, then, not unlikely that what happens in the case of the formation as a whole will be found to occur in the various minor subdivisions of that formation; and I think that this has probably taken place here, thus accounting for the absence of the *Monograptus-scanicus* zone in the southern and south-western portions of the Builth district.

(6) General Summary.

Summing up, we see that in the Builth district there are four main graptolite-zones, the succession being as follows, in descending order :—

(4) Zone of *Monograptus leintwardinensis*, including the probable representatives of the Aymestry Limestone.
(3) Zone of *Monograptus scanicus.*
(2) Zone of *Monograptus Nilssoni.*
(1) Zone of *Monograptus vulgaris.*

(C) The Long Mountain District. (Map, Pl. XXVI.)

(1) Structure and General Features.

The Long Mountain lies directly east of Welshpool, and is formed of a broad syncline of Silurian rocks, ranging from the middle of the Wenlock Shales, through the Lower and Upper Ludlow, to the base of the Old Red Sandstone, a few of the lower beds of which form a shallow outlier on its summit. The area is well defined on all sides: on the north by the Breidden Hills; on the west by the valley of the Severn; and on the south by the Ordovician ground of the Shelve district. On the east the Lower Palæozoic rocks are unconformably overlain by the Carboniferous and Permian formations.

On the Geological Survey maps, a considerable thickness of Wenlock Beds is represented occupying the lower slopes all round the district, while the Ludlows are confined to the high ground near the centre, the small patch of Old Red Sandstone occurring towards the north-eastern extremity. It has long been known, however, since the researches of Prof. Watts, that much of the area mapped as Wenlock Shales belongs rather to the Lower Ludlow formation, but the exact boundary between the two has not hitherto been definitely fixed. My own work in this district has confirmed and extended his research, and his large collection of graptolites, so kindly placed at my disposal, and supplemented by my own, together

with those whose sequence I worked out in the typical Ludlow area, have enabled me to bring the graptolites of the two districts into still greater harmony.

Continuous sections through the Wenlock and Ludlow Beds are fairly numerous in this district, especially on the northern flanks of the mountain, and graptolites are abundant. It is easy, therefore, to fix the position of such graptolitic zones as are recognizable, while the boundary of the Wenlock and Ludlow formations may be mapped with some degree of accuracy.

The rocks are lithologically very similar to those in the Builth district, but in the Long Mountain there is an entire absence of limestones, and the sediments range from thin papery shales on the one hand to hard, sandy, flaggy mudstones on the other.

(2) Northern Area of the Long Mountain.

(*a*) Trefnant-to-Middletown Stream Section. — The most complete section on the north side of the Long Mountain occurs in the brook which flows from Upper Trefnant on the south to near Middletown Railway-station on the north.

As we ascend the section from that station, greyish-black shales containing *Cyrtograptus Lundgreni*, *Monograptus Flemingii* var. δ, etc., occur in the stream-course where it runs parallel with the railway (1 in the map, Pl. XXVI), thus fixing the stratigraphical position of the beds as the highest zone of the Wenlock Shales. There are few exposures until (2) is reached, where a small tributary brook from Glyn Common enters the main stream. Here the beds consist of harder and more flaggy shales, slightly calcareous, giving rise to a well-marked feature. They contain various brachiopods and trilobites, but relatively few graptolites: such as occur being assignable almost exclusively to *M. dubius* and *M. vulgaris*. Similar shales are exposed for a considerable distance up stream, but become increasingly massive and flaggy, and occasionally show concretionary structure (3). *M. vulgaris* is by far the most abundant graptolite, but species of *Orthoceras* and trilobites, etc., are numerous. The graptolites are, on the whole, badly preserved, being rarely seen in true profile, so that it is difficult to be certain of all identifications, and other species may occur besides *M. vulgaris*.

At (4) the main stream follows the general strike of the beds for some distance, but the section is continued along the tributary stream which rises near Upper Trefnant. The shales with *M. vulgaris* are shown along the stream for some distance farther. The direction of dip of the beds varies from south 60° east to south 20° west, but the amount of dip is small and fairly constant.

At (5) the graptolitic fauna becomes more varied, and the beds have yielded *M. bohemicus*, *M. Nilssoni*, *M. uncinatus* var. *orbatus* nov., *M. varians*, *M. dubius*, and *M. vulgaris* var. α. The beds consist of dark grey shales which weather to a light brown. The main stream here bends abruptly to the left, and follows the strike of the beds; but a small tributary brook joins it on the right, and

at (6) occur numerous specimens of the typical *M. Rœmeri.* A few yards higher up (at 7 in the map, Pl. XXVI), a bed is exposed, crowded with specimens of *Monograptus varians, M. Nilssoni,* and *Retiolites spinosus.* This is the only locality in the Long Mountain area at which I have obtained *R. spinosus,* a form so abundant in the Builth district. Finally we have light-brown mudstones containing *M. leintwardinensis* var. *incipiens* nov.

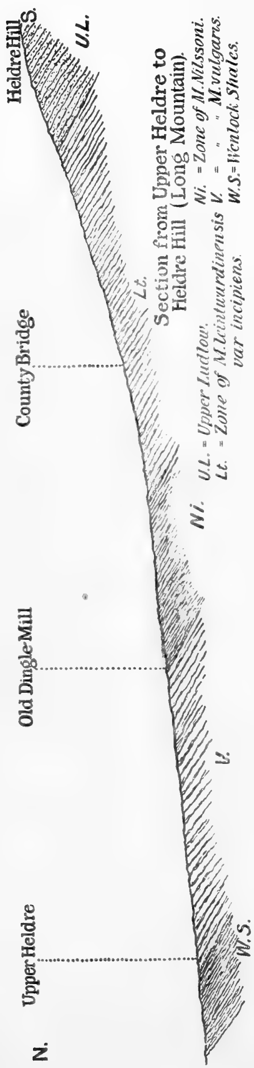


Fig. 8.—(*Approximate scale:* 12 *inches* = 1 *mile.*)

(*b*) Lower Winnington Lane Section.—About ½ mile east of the section just described, a good confirmatory section is shown in the lane near Lower Winnington Farm, but only the middle and upper beds of the Lower Ludlow above the zone of *M. vulgaris* are here laid bare.

The lowest (10) visible consist of thinly-bedded, somewhat papery shales, yielding *M. bohemicus, M. dubius,* etc. A few yards higher up (11) the shales contain *M. varians, M. Nilssoni,* and *M. crinitus,* sp. nov. in abundance, the graptolites almost completely covering the surface of the rock. Above this graptolites are rarer, but *M. varians, M. chimæra,* and *M. uncinatus* var. *micropoma* occur (12). Immediately below the farm the pale flaggy mudstones characteristic of the *M.-leintwardinensis* var. *incipiens* zone come on (13). These are exposed as far as the main road, and their thickness must be at least 300 feet. The succeeding beds become more arenaceous and graptolites practically disappear, their place being taken by brachiopods, trilobites, etc.

The *M.-incipiens* beds are also well seen in an exposure near the Rose & Crown Inn, about ⅓ mile north-east of Winnington Lane. They form the highest prolific graptolitiferous horizon in the district; I have, however, found a few fragments of graptolites at a considerably higher level, showing that the group of the Rhabdophora certainly lingered on in this area for some time longer. The locality

is on the steep hill-slope above Frochas and the County Bridge (14). The graptolites occur in hard micaceous flags, and the specimens are much distorted and fragmentary, so that their identification is uncertain. There is no doubt, however, that they belong to the *Monograptus-leintwardinensis* type, but whether they belong to the typical form or to the *incipiens*-variety is dubious.

(*c*) Confirmatory Sections.—Several other good sections of the Lower Ludlow Beds occur farther west and south-west, and the same general succession of rocks and fossils can be recognized in each. One section, ranging from Dingle Mill to the County Bridge, passes completely through the graptolite-bearing Lower Ludlow Beds from the base of the *M.-vulgaris* zone to the top of the zone of *M. leintwardinensis* var. *incipiens* nov. The *M.-Nilssoni* bed is well shown at the Old Mill. (See fig. 8, p. 442.)

Another complete section is visible in the stream from Trewern Bridge to Ucheldre. I have not personally studied it in detail, but I have examined the various graptolites collected from this section by Prof. Watts, and the sequence is the same as in the Dingle-Mill section. Along the road between Ucheldre and the County Bridge the beds containing *M. leintwardinensis* var. *incipiens* are well exposed, and at one locality (15) *M. ultimus*, Perner, is associated with it.

Still farther south-west another section is exposed along the road from Garbett's Hall to Black Bank. Here the beds immediately succeeding the *M.-vulgaris* zone are relatively poor in graptolites. I have, however, collected from them *M. bohemicus*, *M. Nilssoni*, *M. varians*, *M. uncinatus* var. *micropoma*, and *M. scanicus?*

(*d*) Conclusions.—It is clear from the evidence afforded by the sections exhibited on the northern side of the Long Mountain that the Lower Ludlow formation here presents much the same general palæontological features as in the Builth district. It shows, nevertheless, certain peculiarities of its own. Firstly, the species *M. scanicus*, so characteristic of a special palæontological zone on the Aberedw Hills, is practically absent: I have obtained, it is true, one doubtful specimen from the Garbett's-Hall section. One also occurs in Prof. Watts's collection, but the locality from which it was obtained is unfortunately not certain. The species is, at all events, extremely rare, and is useless, therefore, as a zonal fossil in this district. Secondly, the typical *M. leintwardinensis* has not as yet been found in this area, but its place would seem to be taken by the *incipiens*-variety. It is probable, however, that the horizon marked by the typical form is here unfossiliferous, and that *M. leintwardinensis* var. *incipiens* occupies a lower position in the succession. Thirdly, two new forms, namely, *M. uncinatus* var. *orbatus* and *M. crinitus*, are practically confined to this district, and each of them has been detected at a single locality only. The first of these graptolites has also been found in the Lower Ludlow Beds of Dudley.

With regard to the zonal divisions of the Lower Ludlow formation

in this area, three at any rate of those recognizable near Builth are well developed: that is, the zones of *Monograptus vulgaris*, *M. Nilssoni*, and *M. leintwardinensis*. It may be found convenient in any future mapping of the area to divide the second of these into two sub-zones: (*a*) sub-zone of *M. Nilssoni* and (*b*) sub-zone of *M. Rœmeri*; but the evidence for this division is at present not quite conclusive. The succession is, broadly speaking, as follows:—

(3) Light-coloured flaggy mudstones. Zone of *Monograptus leintwardinensis* var. *incipiens* nov. 900 feet.
(2) Light-coloured thinly-bedded shales.
 (*b*) Zone of *Monograptus Rœmeri*. } 350 to 400 feet.
 (*a*) Zone of *Monograptus Nilssoni*.
(1) Massive flaggy shales. Zone of *Monograptus vulgaris*. 600 to 700 feet.

In the typical Long-Mountain section from Middletown to Upper Trefnant, however, beds containing *M. varians*, *M. Nilssoni*, and *Retiolites spinosus* occur above the *M.-Rœmeri* beds and a short distance below the *M.-incipiens* zone. The presence of these species at so high an horizon is peculiar, and if further research should verify it, then the sub-zone of *M. Rœmeri* can no longer be distinguished. It is possible that the beds are here folded or faulted (as they certainly are locally in other parts of the district), and that the visible succession is consequently not the true one, for I have failed to find these species elsewhere in the district, except at what seems to be a much lower horizon.

The palæontological boundary between the Wenlock and Ludlow formations is marked here, as at Builth, by a change in the lithological characters of the beds, and therefore its exact position in the field can be mapped with considerable accuracy. The upper limit of the Lower Ludlow Beds, on the other hand, cannot be determined on palæontological evidence alone, as the graptolites appear to die out very gradually. But there is a lithological change near the horizon where the graptolites disappear, which coincides fairly well with the boundary drawn by the officers of the Geological Survey between their local Wenlock and Ludlow formations previous to the working out of the graptolites; and this line may be looked upon very naturally as the boundary between the Lower and Upper Ludlow.

(3) Southern Area of the Long Mountain.

The evidence obtained from an examination of the Lower Ludlow graptolites of the southern side of the Long Mountain is by no means so satisfactory as that derived from the study of those of the northern side. The rocks in the southern area on the whole are coarser and more arenaceous, and the graptolites are rarer and more indifferently preserved. So far, however, as I have examined the sections in this southern area, the graptolitic succession agrees well with that in the northern part of the district.

(*a*) Northern Sections.—In this sub-area the lowest horizons of the Ludlow, namely those of the *M.-vulgaris* zone, are well developed in the neighbourhood of Aston Rogers and Aston

Pigot, and at the Workhouse Dingle near Little Worthen. In the beds of the Workhouse Dingle *Monograptus vulgaris* is abundant and is associated with *Retiolites nassa*, Holm, which has not hitherto been recognized elsewhere in Britain. A good section through the Upper Wenlock and Lower Ludlow is exposed along the Brockton Brook, but graptolites are scarce and badly preserved. I have not worked out the section in complete detail, and it may therefore be passed over.

(*b*) Ackley-Llettygynfach Section.—A fairly good section through the Upper Wenlock and Lower Ludlow is exposed along the lane from Lleyn on the south, past Ackley to Llettygynfach, but here again the graptolites are for the most part indifferently preserved and a zonal division of the rocks is at present impossible. The beds for some distance above the Wenlock are not exposed: the lowest visible horizons of the Ludlow contain *M. chimæra* or its variety *Salweyi*, *M. tumescens* and its variety *minor*, and *M. dubius?* The exposure at Llettygynfach Farm is one of the type-localities for *M. tumescens*: it is here the most abundant form, and so far as is known at present occurs only here and at Ludlow. The highest beds in this section have yielded one specimen of *M. leintwardinensis*.

(4) Montgomery-Road Section.

South and west of the Long Mountain itself, but forming practically its longitudinal extension, lies a large area coloured on the Geological Survey maps as Wenlock. I have not worked the country in detail, but a section seen along the road from Montgomery Railway-station to Montgomery Town is worthy of notice.

The beds are much disturbed and are repeated by folds, so that it is difficult to be sure of the order of succession, but two zones are rich in graptolites. The lowest is that of *M. Nilssoni*, with which are associated *M. dubius*, *M. varians*, and fragments of *Retiolites* sp. The higher zone is that of *M. leintwardinensis* var. *incipiens*. The intervening beds are so crushed that it is impossible to obtain any identifiable graptolites from them.

The Ackley-Llettygynfach and Montgomery-road sections were first worked out by Prof. Lapworth, who pointed them out to me when I began to study the graptolite-fauna of the Lower Ludlow Beds, and kindly placed his collections from those localities at my disposal.

(D) Supplementary Districts.

In addition to working over the three areas just described, I have had an opportunity of examining graptolites from the Lower Ludlow Beds of several other districts in Great Britain. Before concluding my remarks on the stratigraphy of the Lower Ludlow formation I will briefly point out to what extent the graptolitic evidence obtained from these supplementary districts confirms the conclusions already arrived at in the Ludlow, Builth, and Long Mountain districts.

(1) The Dee Valley.—My friend and colleague Miss Elles, who visited this district in 1899, has kindly placed her notes and specimens in my hands. She recognized two well-marked graptolite-zones in the Nantglyn Flags, which Mr. P. Lake correlates with the Lower Ludlow Shales, while the zone of *Monograptus leintwardinensis* (typical form) occurs at a considerably higher horizon. The succession is as follows:—

(3) Zone of *Monograptus leintwardinensis.*
(2) Upper Gritty Beds, unfossiliferous.
(1) Nantglyn Flags.
 (*b*) Zone of *Monograptus Nilssoni.*
 (*a*) Zone of *Monograptus vulgaris.*

M. vulgaris occurs in various exposures south of Nant Arddau, while *M. bohemicus* and *M. Nilssoni* are seen in abundance in the gritty bands exposed in the Deeside slate-quarries. The rocks are for the most part too cleaved to make it possible to determine what form of *M. colonus* it is that occurs in association with *M. bohemicus* and *M. Nilssoni* in this zone. It is interesting to find that *M. leintwardinensis* here is the typical form of this species; I have examined specimens from the Llantisilio Road and from Pen-y-Vivod.

(2) The Lake District.—Mr. Marr has kindly permitted me to examine the specimens of Wenlock and Ludlow graptolites collected by himself from the Lake District. At the time when his paper 'On the Wenlock & Ludlow Strata of the Lake District'[1] was published, Barrande's type-forms were uncertain and the Upper Wenlock and Lower Ludlow Beds of the West of England had not been zonally separated, nor had their graptolite-species been clearly defined. Judging from the results now obtained, I should be inclined to group the Ludlow Beds of the Lake District as follows:—

Lower Ludlow	5. Bannisdale Slates.	Zone of *M. leintwardinensis* var. *incipiens.*
	4. Coniston Grits.	Zone of *Monograptus Nilssoni.*
	3. Upper Coldwell Beds.	
	2. Middle Coldwell Beds.	? Zone of *Monograptus vulgaris.*
Upper Wenlock	1. Lower Coldwell Beds.	Zone of *Monograptus Nilssoni* = ? *Cyrtograptus Carruthersi.*

The Middle Coldwell Beds have not hitherto yielded graptolites, and therefore their exact horizon is uncertain. They may possibly represent the zone of *M. vulgaris*, or that species may eventually be detected in the lower part of the Upper Coldwell Beds. The examples of *M. colonus* collected from the Upper Coldwell Beds and Coniston Grits agree more closely than any other British examples known to me with Barrande's most typical form. The specimens of *M. leintwardinensis* from the Bannisdale Slates belong to the variety which I call *incipiens*, and its horizon is the same here as in the Long Mountain district.

[1] Geol. Mag. 1892, pp. 534 *et seqq.*

(3) Southern Scotland.—So far as is known at present the Lower Ludlow Beds of Southern Scotland are non-graptolitic. *Monograptus colonus* has, it is true, been recorded from the Riccarton Beds,[1] and from the Pentland Hills at Habbie's Howe,[2] but its identity with Barrande's *M. colonus* is as yet uncertain.

(4) Dudley.—The Lower Ludlow Shales of the Midlands, intervening between the Dudley and Sedgley Limestones, are not prolific in graptolites. A few, however, have been obtained from time to time by the workmen, and, through the kindness of Dr. Fraser of Wolverhampton, I have been enabled to examine several specimens. Only two species are recognizable:—namely, *M. uncinatus* var. *orbatus* nov. and *M. Rœmeri*; but both are exceptionally well preserved. The exact locality at which the specimens were collected is unfortunately not known.

Some good specimens of *M. Rœmeri* from Dudley are in the Natural History Museum, South Kensington. They probably came from the beds overlying the Dudley Limestone, at one time grouped popularly as Wenlock, but now known to be the representatives of the Lower Ludlow.

(5) The Abberley Hills.—Mr. Wickham King has sent me several specimens of graptolites from the Lower Ludlow of the Abberley Hills for identification: they are all typical Lower Ludlow species. *M. varians* var. *pumilus* is abundant; *M. scanicus* and *M. chimæra* also occur.

V. General Summary.

The Lower Ludlow Shales in Britain, when traced from one district to another, exhibit many variations, not only in lithological characters, but more especially in the thickness of their deposits. Considered as a whole, the beds consist of calcareous mudstones and flags, weathering to a characteristic light-brown; but the sediments become coarser and more arenaceous as they are traced from the south and south-east to the west and north-west, and whereas in the typical Ludlow district the whole thickness of the Lower Ludlow (including the Aymestry Limestone) is only about 1000 feet, in the Lake District it has apparently increased to 10,000 feet.

In spite of the marked variation in vertical extent, however, there is a striking constancy in the sequence of lithological characters of the sediments which distinguish the individual zones, at any rate in the three districts which I have examined in most detail, namely those of Ludlow, Builth, and the Long Mountain. Thus the zone of *M. vulgaris* consists of hard flaggy shales, the zones of *M. Nilssoni* and *M. scanicus* of softer and more shaly material, while that of *M. leintwardinensis* is made up for the most part of hard calcareous

[1] 'Scottish Monograptidæ,' Geol. Mag. 1876, p. 505 & pl. xx, fig. 9.
[2] Mem. Geol. Surv. 'Silur. Rocks of Britain: vol. i, Scotland' (1899) p. 604.

TABLE I, SHOWING THE GEOGRAPHICAL VARIATION IN LITHOLOGY AND THICKNESS OF THE ZONES OF THE LOWER LUDLOW ROCKS.

<table>
<tr><th rowspan="2">ZONES.</th><th rowspan="2">LUDLOW DISTRICT.</th><th colspan="2">BUILTH DISTRICT.</th><th rowspan="2">LONG MOUNTAIN DISTRICT.</th><th rowspan="2">DEE VALLEY.</th><th rowspan="2">LAKE DISTRICT.</th><th rowspan="2"></th></tr>
<tr><th>EASTERN AREA.</th><th>SOUTH-WESTERN AREA.</th></tr>
<tr><td>Zone of Monograptus leintwardinensis.</td><td>Aymestry Limestone (275 feet).
Calcareous laminated flags, passing down into light-brown flaggy mudstones (210 feet).</td><td rowspan="2">Thin calcareous bands and micaceous laminated flags, passing gradually into
Light flaggy mudstones and darker calcareous flags (400 to 500 feet).</td><td rowspan="2">Dark micaceous and calcareous flags, well laminated,
passing gradually into
Light flaggy mudstones.</td><td rowspan="2">Micaceous flags
passing into
Light flaggy
mudstones.
(900 feet ?)</td><td>'Leintwardinensis-Flags.'</td><td>Bannisdale Slates:
[Upper parts calcareous.]
(5000 feet.)</td><td></td></tr>
<tr><td>Zone of M. tumescens, sp. nov.</td><td>Light flaggy mudstones (220 feet).</td><td>Upper Gritty Beds.</td><td>Coniston Grits.</td><td rowspan="4">5000 feet.</td></tr>
<tr><td>Zone of M. scanicus.</td><td>Light flaggy mudstones and shales (100 feet).</td><td>Greyish-brown shales, with some flaggy mudstones (250 feet).</td><td>Unknown.</td><td rowspan="2">Greyish-brown thinly-bedded shales (350 feet).</td><td>[No fossils.]</td><td></td></tr>
<tr><td>Zone of M. Nilssoni.</td><td>More thinly bedded mudstones and shales (120 feet).</td><td>Greyish-brown shales, with thin calcareous bands.
300 feet.</td><td>Greyish-brown shales, with thin calcareous bands (550 feet).</td><td rowspan="2">Nantglyn
Flags.</td><td>Upper Coldwell Flags.</td></tr>
<tr><td>Zone of M. vulgaris, sp. nov.</td><td>Thinly bedded shales. No graptolites. (130 feet.)</td><td>Dark-grey calcareous shaly flags.</td><td>Dark-grey calcareous flags, with conchoidal fracture (100 feet).</td><td>Dark-grey calcareous flaggy shales (600 to 700 feet ?).</td><td>Middle Coldwell (?).</td></tr>
<tr><td></td><td>Wenlock Limestone.</td><td>Wenlock Shales. (Zone of Cyrtograptus Lundgreni.)</td><td>Wenlock Shales.</td><td>Wenlock Shales.</td><td>Moel Ferna Slates.</td><td>Lower Coldwell (?).</td><td></td></tr>
</table>

splintery flags. Speaking generally, there is a gradual decrease of argillaceous material as the beds are followed from base to summit of the series (for detailed comparison see Table I, p. 448).

With regard to the distribution of the Lower Ludlow graptolites, it may be pointed out that some forms, as, for instance, *Monograptus Nilssoni* and *M. bohemicus*, are very widely distributed over Britain and Europe. Some appear to be associated only with sediments of a particular lithological character, as, for example, *M. scanicus*, which occurs in Scania and the southern and south-eastern districts of Britain, but is rare or absent in the northern and north-western areas. Some forms again seem to be quite local, as, for instance, *M. crinitus*, which is practically confined to the Long Mountain district.

It is hardly surprising, therefore, to find that of the five graptolitic zones which may be recognized in one or other of the several British districts, only two, those of *M. Nilssoni* and *M. leintwardinensis*, are common to them all. The zone marked by *M. vulgaris*, although persistent in those areas where there is a little or no development of purely calcareous sediments, is unknown in the Ludlow district. The zone marked by *M. scanicus* is well shown in two districts, namely, those of Ludlow and Builth (eastern area), but in other districts it is either wanting in graptolites or else the zone-fossil is absent. The zone of *M. tumescens* is confined to two areas, namely, those of Ludlow and the south side of the Long Mountain, but in these it occurs in great abundance.

As respects the distribution of the graptolites in these several ones, an examination of Table III (p. 450) shows clearly that the great majority occur in association in the zones of *M. Nilssoni* and *M. scanicus*, while all the other zones yield only a few species.

Regarding the limits of the Lower Ludlow Shales, we have seen that the boundaries based on purely lithological characters are artificial, for the Wenlock and Aymestry Limestones are confined to special areas. Any natural and universally applicable division must be determined by palæontological considerations. Such a division necessitates, in my opinion, the inclusion of the Aymestry Limestone in the Lower Ludlow formation.

No detailed comparison with the Lower Ludlow deposits of Europe is at present possible, as no zonal work has been done in these beds outside Britain. A glance at Table II (facing p. 450), however, will show that many of the species of Lower Ludlow graptolites found in Britain occur in Scania, Bohemia, Germany, and France. One awaits with interest the forthcoming section of Perner's 'Études sur les Graptolites de Bohême,' dealing with the zonal divisions of the graptolitic rocks of Bohemia, the graptolites of which seem to be so closely allied to those of Britain.

TABLE III, SHOWING THE ORDER OF APPEARANCE OF THE GRAPTOLITES OF THE LOWER LUDLOW BEDS OF BRITAIN.

[C=Very common; c=common; r=rare.] SPECIES.	Zone of *M. vulgaris.*	Zone of *M. Nilssoni.*	Zone of *M. scanicus.*	Zone of *M. tumescens.*	Zone of *M. leintwardinensis.*
Monograptus leintwardinensis, Hopk.	...	...	...	...	c
——— ——— var. *incipiens* nov.	...	...	...	...	c
M. ultimus, Perner	...	...	...	...	r
M. tumescens, sp. nov.	...	...	c	c	
——— ——— var. *minor* (M'Coy)	...	...	c	c	
M. bohemicus (Barr.)	...	C	c	r	
M. chimæra (Barr.)	...	c	C	r	
——— ——— var. *a*	...	?	c		
M. Rœmeri (Barr.)	...	r	c		
M. scanicus, Tullb.	...	c	c		
M. varians var. *pumilus* nov.	...	C	C		
M. chimæra var. *Salweyi* (Hopk.)	...	c			
M. colonus (Barr.)	...	C			
——— ——— var. *compactus* nov.	...	r			
M. comis, sp. nov.	...	r			
M. crinitus, sp. nov.	...	r			
M. gotlandicus, Perner	...	r			
M. Nilssoni (Barr.)	...	C			
M. uncinatus var. *micropoma*, (Jækel)	...	r			
M. uncinatus var. *orbatus* nov.	...	r			
M. varians, sp. nov.	...	c			
——— ——— var. *a*	...	r			
——— ——— var. *β*	...	c			
M. vulgaris var. *a* nov.	...	c			
——— ——— var. *β* nov.	...	r			
Retiolites spinosus, sp. nov.	...	C			
M. dubius (Suess)	C	c	c		
M. vulgaris, sp. nov.	C				
Retiolites nassa, Holm	r				

VI. PALÆONTOLOGY.

(A) General Characters of the Graptolite-Fauna of the Lower Ludlow Formation.

Some of the more typical species of graptolites now known to be characteristic of beds of Lower Ludlow age have long since been described and figured by Murchison, Barrande, Suess, and others; but owing to the imperfect state of knowledge of graptolites in general, at the time when the original type-specimens were named, many of the subsequent identifications were necessarily provisional,

RAPTOLITES IN THE

T. DISTRICT. ...ide.	S. side.	MONTGOMERYSHIRE
Zone of *M. leintwardinensis* var. *incipiens.*	Llettygynfach and Worthen District.	Montgomery Road and Llanfair.
...	*	*
...	...	..
...	*	
...	*	
*	...	...
...	*	..
...	...	...
...	...	..
...	...	*
...	...	.
...	...	*
...	...	.
...	...	...
...	...	...
...	...	...
...	...	...
*	...	*
...	...	..
...	?	...
...	...	..
...	...	..
...	...	..
...	...	..
..	*	.
...	...	*

TABLE II, SHOWING THE DISTRIBUTION OF GRAPTOLITES IN THE LOWER LUDLOW BEDS OF BRITAIN AND EUROPE.

SPECIES.	LUDLOW DISTRICT. Zone of *M. Nilssoni*.	Zone of *M. scanicus*.	Zone of *M. tumescens*.	Zone of *M. leintwardinensis*.	BUILTH DISTRICT. Zone of *M. vulgaris*.	Zone of *M. Nilssoni*.	Zone of *M. scanicus*.	Zone of *M. leintwardinensis*.	LONG MT. DISTRICT. North side. Zone of *M. vulgaris*.	{ Sub-zone of *M. Nilssoni*. { Sub-zone of *M. Ræmeri*.	Zone of *M. leintwardinensis* var. *incipiens*.	S. side. Llettygynfach and Worthen District.	MONTGOMERYSHIRE. Montgomery Road and Llanfair.	DEE VALLEY. Nantglyn Flags.	'*Leintwardinensis*'-Beds.	LAKE DISTRICT. Coldwell Beds.	Bannisdale Slates.	ABBERLEY HILLS. Ludlow Shales.	DUDLEY. Sedgley Shales.	SCANIA. *Cardiola*-Skiffer.	BOHEMIA. Etage Ee 1? Ee 2 or Colonies.	FRANCE. Languedoc, Bretagne, etc.	GERMANY. Graptolithengestein (Drift).
Genus *Monograptus*.																							
Group I. Type *M. dubius*.																							
Monograptus comis, sp. nov.	*																						
—— *dubius* (Suess)	*	*	.		*	*	*		*	*		*	*	*		*				*	*		
—— *gotlandicus*, Perner	.	...	.		..	...	...		..	*								..		*	*		
—— *tumescens*, sp. nov.	.	*	*		...	..			.	...	.	*											
—— —— var. *minor* (M'Coy)	...	...	*	..	...	...	...		.	..	..	*											
—— *ultimus*, Perner	...	...	.	...	...	...	...			...	*			..		.	*				*		
—— *vulgaris*, sp. nov.	..	...	..	..	*	...	...	..	*	..	.	*		.	..		.			.	?		
—— —— var. α	*	...	...	..	...	...	..	..	...	*													
—— —— var. β	...	..	...		..	..	..	.		*													
Group II. Type *M. colonus*.																							
M. colonus (Barr.)	*	..	...		..	*			.					?		*	...			*	*	*	
—— —— var. *compactus* nov.	*	...							.					..				*					
—— —— var. *ludensis* (Murch.)	...		.										*										
—— *Ræmeri* (Barr.)	*	*			.		*			*						?			*	?	*	*	
—— *varians*, sp. nov.					..	..	.		.	*			*										
—— —— var. α	*																						
—— —— var. β	*																						
—— —— var. *pumilus* nov.	*	*	.		.	...	...		.									*					
Group III. Type *M. chimæra*.																							
M. chimæra (Barr.)	*	*	*		...	...	*			*		..				...		?			*		?
—— —— var. α		*		.	...							...		.	.	...		...		*			
—— —— var. *Salweyi*, Hopk.	*					...			.							...		.					?
—— *leintwardinensis*, Hopk.		.		*		..		*		.	.				*	...	.			*			
—— —— var. *incipiens* nov.	..		.	..	.	...	.	...	.		*		*		...	...	*				*		
Group IV. Type *M. uncinatus*.																							
M. uncinatus var. *micropoma*, Jækel.	*	.	.			...	.	.	.	*	.	..	.		.	...			..				*
—— —— var. *orbatus* nov.	...	.	..	..	..	...	...	..	...	*	.	?		.	..	.	...	.	*				
Group V. Type *M. scanicus*.																							
M. crinitus, sp. nov.	..		..	..	..					*													?
—— *scanicus*, Tullb.	*	*	...	...	.	...	*		..	?		...			..			*	.	*			*
Group VI. Type *M. Nilssoni*.																							
M. bohemicus (Barr.)	*	*	*	..		*	*			*	..			*	...	*			.	*	*	*	*
—— *Nilssoni* (Barr.)	*	*	...	..	...	*	..			*				*	...	?	...		..	*	*	*	*
Genus *Retiolites*.																							
R. nassa, Holm	...	...	..				...					*		.	..				.	*	*		
R. spinosus, sp. nov.	...	...	...			*				*	.	.	*	..	.			.			*		

and, as we are now aware, frequently incorrect. Consequently the graptolite-fauna of the formation stands greatly in need of revision.

The graptolitic species of the Lower Ludlow Beds show many resemblances among themselves, and the graptolite-fauna as a whole presents certain peculiarities of its own. In the first place, the polypary, in the large majority of the forms, is straight for the greater part of its length, but is distinctly curved inward at the proximal extremity. This shape of the polypary is almost peculiar to the Lower Ludlow graptolites, and stands in marked contrast to that of the Wenlock-Shales graptolites, which as a rule is curved outward proximally.

Secondly, the shape of the thecæ is strangely similar in most Lower Ludlow species. The apertures are either spinose, or they are wholly destitute of ornamentation. The development of the apertural spines appears to have been gradual and also subject to variations, for not only is there every gradation between species which possess only a single apertural spine and those that have all their thecæ spinose, but even in the same species the number of spines is variable. The development of spines would seem to be the expression of an instinct of preservation, and it is interesting to note that the later forms of trilobites show similar characters. This leads one to infer that the extermination of both graptolites and trilobites may have been due not merely to unfavourable physical conditions but also to the existence of powerful enemies.

In spite, however, of the general similarity in form of the Lower Ludlow graptolites, a further and more complete examination of the fauna reveals the existence of a large number of species and varieties. The separation of these is difficult, for as the number of specimens examined is increased, the more is one induced to accept the views of those who assert that species and varieties merge the one into the other by almost imperceptible gradations. It would be useless for the purposes of this paper to describe all the various transitional forms, and I shall therefore confine myself to describing and naming (*a*) those which are of zonal value in working out the stratigraphy of the Lower Ludlow Beds; and (*b*) those of special palæontological interest.

As regards the classification of the species and varieties, it is found to be most convenient to group them round special types. The character which I consider to be of most value for the purposes of such grouping is undoubtedly that of the proximal extremity, for it is more constant than any other and appears to be less liable to variations. In the present general state of our knowledge, however, other characters, such as the form of the polypary and the shape of the thecæ, must still in many cases be the main guide in classification, for we must assume provisionally that the general morphology of the form is the best index of phylogenetic relationship.

The Lower Ludlow graptolite-fauna includes two families and two genera, namely *Monograptus* and *Retiolites*, while two families and three genera are contained in that of the Wenlock Shales below.

The genus *Monograptus* is represented in the Lower Ludlow by fifteen well-marked species and thirteen varieties, while of the genus *Retiolites* there are only two species. The following is a list of the species and varieties described in this paper :—

Genus MONOGRAPTUS. Group I. Type *M. dubius* (Suess).
M. dubius (Suess), *M. vulgaris*, sp. nov., *M. vulgaris* var. *a*, *M. vulgaris* var. *β*, *M. tumescens*, sp. nov., *M. tumescens* var. *minor* (M'Coy), *M. gotlandicus*, Perner, *M. comis*, sp. nov., and *M. ultimus*, Perner.

Group II. Type *M. colonus* (Barr.).
M. colonus (Barr.), *M. colonus* var. *ludensis* (Murch.), *M. colonus* var. *compactus* nov., *M. varians*, sp. nov., *M. varians* var. *a*, *M. varians* var. *β*, *M. varians* var. *pumilus* nov., and *M. Rœmeri* (Barr.).

Group III. Type *M. chimæra* (Barr.).
M. chimæra (Barr.), *M. chimæra* var. *Salweyi* (Hopk.), *M. chimæra* var. *a*, *M. leintwardinensis*, Hopk., and *M. leintwardinensis* var. *incipiens* nov.

Group IV. Type *M. uncinatus*, Tullb.
M. uncinatus var. *orbatus* nov., and *M. uncinatus* var *micropoma* (Jækel).

Group V. Type *M. scanicus*, Tullb. [sub-group of *M. lobiferus* (M'Coy)].
M. scanicus, Tullb., and *M. crinitus*, sp. nov.

Group VI. Type *M. Nilssoni* (Barr.).
M. Nilssoni (Barr.) and *M. bohemicus* (Barr.).

Genus RETIOLITES. *R. nassa*, Holm, and *R. spinosus*, sp. nov.

Of the six groups of *Monograptus* enumerated in the foregoing list, the first two, those of *M. dubius* and *M. colonus*, are by far the most important, and both are rich in species and varieties. The separation of these two groups has been almost entirely determined by the character of the proximal extremity, for the general form of the polypary and the shape of the thecæ are much the same in both groups. Although the group typified by *M. colonus* is the more characteristic of the Lower Ludlow Shales, being entirely confined to them, yet I place the group of *M. dubius* first, as it is the more primitive of the two and is well represented in the underlying Wenlock Shales.

The separation of the group of *M. chimæra* as distinct from that of *M. colonus* must be regarded as provisional: for the presence or absence of thecal spines, as I have already pointed out, seems to be in many forms dependent on external conditions, and therefore can hardly be considered of great classificatory value.

The remaining three groups, those of *M. uncinatus*, *M. scanicus*, and *M. Nilssoni*, are individualized almost entirely by the character of the thecæ and the form of the polypary. Such grouping is admittedly unsatisfactory and provisional, but these groups are so poorly represented in the Lower Ludlow Beds that there is not sufficient evidence available for a more complete and exact classification. I am of opinion, however, that further research will show the advantage of placing species with such distinct proximal extremities as *M. Nilssoni* and *M. bohemicus* in separate groups; and possibly of uniting *M. scanicus* and *M. Nilssoni* in the same group on account of the similarity of their siculæ.

When we compare the graptolite-fauna of the Lower Ludlow as now worked out, with that of the Wenlock Shales below, the sup-

posed great palæontological break between them all but disappears. It is true that only one or two species are common to both, but most of the groups of graptolites occurring in the Lower Ludlow Beds are met with in the Wenlock Shales, and the remainder appear to represent the natural and gradual development of allied Wenlock groups. Thus the group of *Monograptus dubius*, already occurring in the Wenlock, survives undiminished in the Ludlow, and the groups of *M. scanicus* and *M. uncinatus* are also represented in both formations. The groups of *M. colonus* and *M. chimæra* are probably only developments of that of *M. dubius*. Even *Retiolites* is common to both the Wenlock and Ludlow formations. *Cyrtograptus*, as such, is unknown in the Lower Ludlow, yet this genus, so valuable for stratigraphical purposes in the Wenlock, may perhaps be regarded rather as a temporary reversion than as a constant biological genus, seeing that in one instance at least—namely that of *Cyrtograptus Carruthersi* and *Monograptus Nilssoni*—the two forms appear to be identical in all respects, except in the matter of branching.

Notes on Terminology, etc.

The following notes have been drawn up for the purpose of making clear the exact meaning of the various terms and measurements used in the description of the species:—

1. Owing to the difficulty of observing the exact point of origin of the first theca from the sicula in compressed specimens, its position as here stated is the apparent one only. Thus, in those species which belong to the group of *M. dubius*, the first theca probably arises above the aperture of the sicula; but its outer wall invariably grows downward, and so appears to arise from the base.
2. In most species it is found that the number of thecæ per inch in the proximal part of the polypary is greater than that in the distal part. Two numbers therefore are given throughout, the first referring to the proximal and the second to the distal end. The first number is obtained by doubling the numbers counted in the proximal half-inch, and similarly with the second.
3. The length of the theca as given is that of the lower thecal wall, but the amount of overlap is (according to general practice) measured from the upper thecal wall.
4. The various measurements tabulated in the description of a species are the average of those taken from one or two typical specimens; thus although the actual numbers may not hold for other specimens, yet the relative proportions are the same for all.
5. The associates of a species, as here enumerated, are those which have been actually found with it on the same slab.

(B) Description of the Graptolite-Species.

1. Genus *Monograptus*.

(a) Group 1. Type *M. dubius* (Suess).

1. Thecæ of one type only.
2. Outer wall of first theca extending down to the aperture of the sicula and inclined to it at a small angle (20° to 30°).
3. Length of adult theca, as a rule, 2 or 3 times the width.

The first two characters are by far the most important for the

purposes of separating the species belonging to the groups of *Monograptus dubius* and *M. colonus.* The relative width and length of the thecæ vary considerably in different species, and are in some cases the same in the one group as in the other. It is impossible to identify a species belonging to either of these groups without a careful examination of the proximal end of its polypary.

Monograptus dubius (Suess). (Pl. XXV, figs. 1 A & 1 B.)

1851. *Graptolithus dubius*, Suess, 'Ueber Böhmische Graptolithen' Haidinger's Abhandl. vol. iv, pt. iv, p. 115 & pl. ix, figs. 5 *a–b*.

(Note.—The synonymy of the several species will be found on p. 487.)

This is typically a Wenlock form, but as it ranges up into the Ludlow Beds I here give a brief description of it, drawn from specimens found in the *M.-Nilssoni* zone of the Montgomery-road section and in the Ludlow district.

Polypary.—Attains a length of 10 cm. (4 inches). Straight for the greater part of its length, but for the first five or six thecæ slightly curved inward. Width at proximal end = about ·76 mm. (·03 inch); maximum width = only 2 mm. (·08 inch); increase in width gradual throughout the polypary, but rather more rapid for the first few thecæ. Distal prolongation of the virgula rarely seen, owing to the great length of the polypary.

Proximal Extremity.—Sicula 1·77 mm. (·07 inch) long and ·42 mm. (·017 inch) in diameter at the apertures, hence $4\frac{1}{2}$ times as long as wide. Aperture concave and slightly contracted, with a short curved ventral spine. Apex of the sicula extending to just below the aperture of the second theca, and the outer wall of the first theca reaching to the base of the sicula and inclined to it at a low angle of 20°.

Fig. 9.—M. dubius, *proximal extremity showing the sicula.* (×5.)

[Enlargement of fig. 1 A in Pl. XXV.]

Thecæ.—Twenty-five to twenty in the inch (ten to eight in 1 cm.), inclined to the axis at an angle of 30° to 35°. All of the same type; fairly long and broad tubes, 2 or 3 times as long as wide, and overlapping for from a third to a quarter of their length. Length of an adult theca = 2·54 mm. (·1 inch). Thecal apertures round or slightly oval, provided with a blunt denticle, generally ornamented with a small spine.

M. dubius is readily recognized by the shape and number of its thecæ, but it often varies considerably in the general form of the polypary. At some horizons in the Wenlock Shales it rarely exceeds 2·54 to 3·8 cm. (1 to 1·5 inches) in length, and has a long distal prolongation of the virgula; at others again, it reaches a length of

8·9 to 10 cm. (3½ to 4 inches) and is somewhat broader. In all cases, however, the shape of the thecæ is the same, and it seems impossible to separate the extreme types in the present state of our knowledge.

One form belonging to the group typified by *Monograptus dubius*, from the Lower Ludlow Beds of the Ludlow district, has been figured as *M. serra*, Hopk.; but, after a careful examination of numerous specimens, I find that I am unable to separate it from *M. dubius*, even as a distinct variety. This may possibly be done when the characters of *M. dubius* are more clearly defined. The slightly spinose apertural denticle so characteristic of *M. serra* is equally well marked in specimens of *M. dubius* from the Wenlock Shales of Builth. The Bohemian form figured by Dr. Perner as *M. dubius*[1] also exhibits this character quite as distinctly. The original figure of *M. dubius* given by Suess is a very indifferent one, but in spite of this the graptolite appears to have been as a rule correctly identified by British geologists. Dr. Perner has recently refigured and described Suess's type-specimen, and the British forms agree well with it.

Foreign Localities.—Bohemia (Vyskočilka, Kuchelbad, Kozel, Borek, etc.); Sweden (Röstånga, Tomarp, Tibaröd); Harz Mountains, etc.

British Localities.—Ludlow district (Elton Lane, Stormer Hall, Elton-Ludlow Road, etc.); Builth (Aberedw Hill, etc.); Long Mountain (Glyn Brook, etc.); Lake District (Moughton); Southern Scotland (Riccarton and Hindhope).

Horizon.—Lower Ludlow Shales (zones of *M. vulgaris*, *M. Nilssoni*, and *M. scanicus*). It also occurs in the Wenlock Shales.

Associates.—*M. Nilssoni*, *M. bohemicus*, *M. scanicus*, *M. chimæra* var. *Salweyi*, *M. uncinatus* var. *micropoma*, *M. varians* and its variety *pumilus*, *M. vulgaris*.

Monograptus vulgaris, sp. nov. (Pl. XXV, fig. 2.)

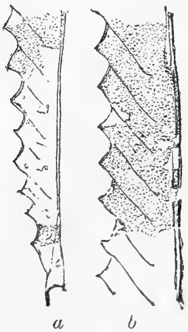
Polypary attaining a length of 5 to 10 cm. (2 to 4 inches) or even exceeding that length. Straight at the proximal end, except for a slight incurve of the first three or four thecæ; when about half the length is reached the polypary curves gently, so that the outer margin is slightly concave. Form of the polypary very characteristic, recalling that of *M. Rœmeri*. Virgula prolonged for a short distance distally. Width at the proximal end = about ·76 mm. (·03 inch), increasing to a maximum width of 2·54 mm. (·1 inch) at the distal end. Increase in width most rapid for the first 12·7 or 19 mm. (·5 or ·75 inch), at the rate of about ·127 mm. (·005 inch) for each theca; after this the increase is more gradual until the distal extremity is reached.

Proximal Extremity.—Most characteristic, serving to distinguish this species readily from all others related to it. Sicula about 2 mm. (·08 inch) long, ·5 mm. (·02 inch) wide at the aperture, hence only 4 times as long as wide; inner wall of the

[1] 'Études sur les Graptolites de Bohême' pt. iii, sect. *b* (1899) pl. xiv, fig. 11.

sicula prolonged as a coarse curved spine about 5 mm. (·02 inch) in length. The first theca, 1 mm. (·04 inch) long, arises distinctly above the aperture of the sicula, being inclined to it at an angle of about 30°. The sicula extends to the level of the lower edge of the aperture of the second theca.

Fig. 10.—M. vulgaris, *sp. nov. from Trefnant-Middletown Brook, Long Mountain. (× 5.)*



[*a*=Proximal extremity, with sicula.
b=Distal thecæ.]

Thecæ.—Twenty-eight to twenty-four in the inch (eleven to nine in 1 cm.), inclined to the axis at angles of 35° to 40°. They vary considerably in shape according to the manner of preservation, but appear to be midway between those of *M. dubius* and *M. colonus.* The more proximal thecæ are short and wide tubes not quite twice as long as wide, with widened apertures of the typical *M.-dubius* type. Adult thecæ considerably longer, measuring 2·75 mm. (·11 inch), and 4 times as long as wide. Increase of length and relative decrease of width of the thecæ very gradual. Amount of overlap nearly one half (in the distal thecæ).

Affinities.—*M. vulgaris* may be readily distinguished by

(*a*) Its comparatively large size;
(*b*) The general shape of the polypary;
(*c*) The character of the proximal end; and
(*d*) The character of the thecæ.

The only species to which it is allied and with which it might be confused is *M. largus*, Perner. It is somewhat difficult to determine correctly the characters of this Bohemian species, as the figures are not quite in agreement with Dr. Perner's brief description. Thus he states the width at the proximal end to be 1·7 mm., whereas the width, as measured from his fig. 23 (*op. cit.* pl. xiv), is ·85 mm., and none of his figures show a width exceeding 2·8 mm. (5 mm. in description). The Bohemian species appears, however, to be considerably larger than the English form. Again, the polypary is said to be straight, except at the proximal end, which shows a greater incurve than do the English specimens, and the adult thecæ are relatively shorter and broader. Dr. Perner, unfortunately, does not figure the sicula complete, which would enable one to determine the identity or otherwise of these two forms. *M. vulgaris* approximates closely to the form figured by Dr. Perner (*op. cit.* pl. xvii, fig. 17), and provisionally referred to *M. dubius*, in general form and shape. The sicula also appears to be somewhat similar, but there are only twenty or nineteen thecæ in the inch as against twenty-eight to twenty-four (eleven to nine in 1 cm.). It is easily distinguishable from all other English forms.

Monograptus vulgaris is of considerable palæontological interest, for it possesses characters which ally it both with the *M.-dubius* and the *M.-colonus* groups. This is well seen, not only in the shape of the thecæ, but also in the character of the proximal end: the first theca being inclined to the sicula at a low angle as in *M. dubius*, yet arising above the aperture as in *M. colonus*.

Localities.—This species occurs most abundantly in the Long Mountain district, but I have also found it at Builth, and Miss Elles has recognized it in the Dee Valley.

Horizon.—*M. vulgaris* is the characteristic graptolite of the lowest zone of the Lower Ludlow.

Associates.—*M. dubius* and *Retiolites nassa.*

M. vulgaris has a considerable range in time, and undergoes certain modifications as we follow it higher up the succession. If the specimens of *M. vulgaris* were in a more satisfactory state of preservation, I believe that it would be possible to trace the gradual stages in the evolution of this species, from the type-form at the base of the succession, through the various horizons of the Ludlow Shales, to the well-marked varietal forms at the top. Two distinct varieties characteristic of the higher horizons may be here distinguished.

Var. α nov. (Pl. XXV, fig. 3.)

This variety is distinguished from the typical form by

(1) The shape of the adult thecæ, which are relatively broader and only 3 times as long as wide, and therefore more distant;
(2) The general shape of the polypary, which is straight distally and more incurved proximally, and seldom, if ever, exceeds 5 cm. (2 inches) in length.

Localities.—Long Mountain (Trefnant-Middletown Brook, etc.); Ludlow district (Elton Lane?).

Horizon.—Zone of *M. Nilssoni.*

Associates.—*M. Nilssoni, M. uncinatus* var. *orbatus, M. colonus* var. *compactus, M. varians.*

Var. β nov. (Pl. XXV, fig. 4.)

This variety is distinguished from the typical form by

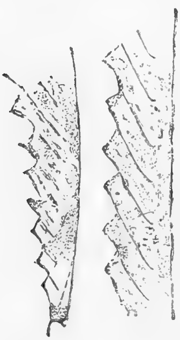
(1) Its greater narrowness, the maximum width rarely attaining 2 mm. (·08 inch);
(2) The general form of the polypary, which has a strong proximal curvature and straight distal portion;
(3) The character of the proximal end: the sicula is nearly 5 times as long as wide, and the first theca appears to arise rather nearer the sicular aperture;
(4) The form of the thecæ: they are shorter and narrower, and their apertures appear to be slightly oblique to the direction of the thecæ.

It occurs on the north side of the Long Mountain, at Lane Farm, in association with *M. bohemicus*, in the zone of *M. Nilssoni*, or possibly in the sub-zone of *M. Rœmeri.*

Monograptus tumescens, sp. nov. (Pl. XXV, figs. 5 A & 5 B.)

Polypary from 2·5 to 3·8 cm. (1 to 1·5 inch) long, straight for the distal four-fifths of its length, but the proximal one-fifth is strongly incurved, making an angle of 10° or more with the general direction of the polypary. Width at the aperture of the first theca =about ·76 mm. (·03 inch), increasing rapidly for the first three or four thecæ, at the rate of ·38 mm. (·015 inch) for each theca, then more gradually, the maximum width of 2 mm. (·08 inch) being attained from the seventh to the tenth theca. From that point the width decreases slightly, so that throughout the distal part the width is only 1·77 mm. (·07 inch), thus giving the polypary a characteristic form. The virgula, is so far as I have observed, not prolonged beyond the distal extremity.

Fig. 11.—M. tumescens, *sp. nov.* (×5).



a *b*

[*a*=Enlargement of proximal extremity of fig. 5 A in Pl. XXV.
b=Distal thecæ of a specimen from Llettygynfach.]

Proximal Extremity.—Sicula about 1·9 mm. (·075 inch) long and ·38 mm. (·015 inch) wide at the aperture, hence it is 5 times as long as wide. Aperture concave, somewhat contracted, and provided with a long ventral spine. Proximal extremity in other respects similar to that of *M. dubius*.

Thecæ.—Twenty-eight to twenty-four in one inch (eleven to nine and a half in 1 cm.), inclined to the axis at an average angle of about 30°; proximal thecæ less highly inclined than the distal. All approximately similar in form, being long and wide tubes with straight or slightly concave apertures at right angles to the direction of the thecæ, with an acute denticle, but devoid of spines. Adult thecæ about 2·54 mm. (·1 inch) long, and 4 times as long as wide; the first theca is only about 3 times as long as wide. The adult thecæ overlap for from one-third to one-half of their length.

This form is one of the many which have been assigned to *M. colonus* (Barr.). It will be evident, however, when the foregoing characteristics are taken into consideration, that it is quite distinct from all other species: its general form, and the disposition and general characters of the thecæ distinguishing it readily. In the shape of the polypary it approaches somewhat closely to *M. subcolonus*, Perner, though it differs in the number and shape of the thecæ. It bears some resemblance to *M. frequens*, Jækel, but the identity of that species is doubtful.

Localities.—Long Mountain (south side at Llettygynfach); Montgomery Road; Ludlow district (Elton Lane and Elton–Ludlow Road).

Horizon.—It is the characteristic fossil of the *M.-tumescens* zone near the top of the Lower Ludlow Shales. Forms almost identical with it, however, occur in the lower zones of the Ludlow.

Associates.—*Monograptus tumescens* var. *minor*, *M. chimæra* (very rare), *M. bohemicus* (very rare).

Var. *MINOR* (M'Coy), non *Monograptus ludensis*. (Pl. XXV, figs. 6 A & 6 B.)

1855. *Graptolites ludensis* var. *minor*, M'Coy, 'Brit. Palæoz. Foss.' p. 5.

M'Coy described under this name a 'species resembling' *M. ludensis*, 'but of only half the width, yet having from four to five denticles in a space of two lines.' I have been unable to obtain specimens from M'Coy's type-locality at Llangynyw Rectory (Montgomeryshire), but from specimens formerly in Nicholson's collection, and now in Prof. Lapworth's possession, I am inclined to the opinion that the form here described is identical with M'Coy's variety.

M. tumescens var. *minor* agrees with the typical *M. tumescens* in

(1) The character of the proximal extremity; and
(2) The shape of the thecæ.

It differs from it in

(1) Its small size, never exceeding 12·7 mm. (·5 inch) in length, and measuring generally less;
(2) The form of the polypary.

Localities.—Long Mountain (Llettygynfach); Ludlow district (Elton-Ludlow Road, Elton Lane); Llangynyw Rectory (Montgomeryshire).

Associate.—*M. tumescens.*

I have had the opportunity of examining only one of the specimens which Nicholson collected from the Lake District, and described as *M. colonus*. This is now in Prof. Lapworth's collection at Mason University College, Birmingham. Unfortunately, it is by no means well preserved. I have, however, found others very similar in the Ludlow district (Elton Lane, etc.), and the form is evidently closely allied to, if not identical with, the species which I have described as *M. tumescens*. The Lake District form is shorter and stouter than the typical *M. tumescens*, and the thecæ are more close-set, thirty-three to thirty in the inch (thirteen to twelve in 1 cm.). They may all belong to a distinct variety of *M. tumescens*, but at present there is not sufficient evidence to decide this point.

MONOGRAPTUS COMIS, sp. nov. (Pl. XXV, figs. 8 A & 8 B.)

Polypary barely 2·5 cm. (·07 inch) in length. Straight for the distal half of its length, curving inward distinctly in the proximal half. Increase in width, from ·5 mm. (·02 inch) to 1·27 mm. (·05 inch), gradual throughout the polypary. In the only specimen that shows the distal end, the virgula is slightly produced beyond the terminal theca.

Proximal Extremity.—Sicula probably about 1·77 (·07 inch) long, and its apertural width = ·38 mm. (·015 inch). The first theca arises distinctly above the aperture of the sicula, but grows down so as almost to reach the aperture.

Fig. 12.—*Monograptus comis*, *sp. nov.* (×5).

[Enlargement of the proximal extremity of fig. 8 A in Pl. XXV.]

Thecæ.—Twenty-nine or twenty-eight in 1 inch (eleven and a half to eleven in 1 cm.), inclined to the axis at an angle of 25° to 30°; straight tubes, uniform in width throughout; the adult thecæ are 1·77 mm. (·07 inch) long, and from 3 to 4 times as long as wide. Proximal thecæ in contact merely, or with a slight overlap in the distal thecæ. Lower free wall concave or straight. Apertures concave, the lower wall prolonged into a pointed denticle bending outward and slightly downward, but with no actual spine.

This graceful species is readily distinguished by (*a*) its general form and (*b*) by the character of the thecæ. The proximal extremity shows that it belongs to the group of *M. dubius*. In other respects *M. comis* has no marked resemblance to any other species.

Localities.—Ludlow district (Elton–Evenhay Lane).

Horizon.—Zone of *M. Nilssoni*.

Monograptus gotlandicus, Perner. (Pl. XXV, fig. 7.)

1890. *Monograptus* sp., Holm, 'Gotlands Graptoliter' Bihang till K. Svensk. Vet.-Akad. Handl. vol. xvi, pt. iv, no. 7, p. 17 & pl. i, figs 27–30.

1899. *Monograptus gotlandicus*, Perner, 'Études sur les Graptolites de Bohême' pt. iii, sect. *b*, p. 12 & pl. xiv, fig. 22.

Hitherto only small fragments of this species have been figured, and these only of the distal end; the proximal extremity has never been either described or figured, nor has the general form of the polypary been given. Any identification with this species must be, therefore, a matter of doubt, and it is with some hesitation that I identify the following form with the fragmentary specimens figured by Holm and Perner.

Polypary.—3·2 mm. (1·25 inch) long, and straight distally, but with a slight incurve at the proximal end. Width at the proximal end = ·76 mm. (·035 inch), increasing gradually to a maximum width of 2·03 mm. (·08 inch) at the rate of ·01 mm. (·004 inch) for each theca. Distal end incomplete.

Proximal Extremity.—Exact length of sicula not seen, but it is probably about 2·03 mm. (·08 inch) long and ·35 (·014 inch) wide at the aperture, which is strongly concave and has a long curved ventral spine. The first theca seems to extend nearly to

the base of the sicula, being inclined to it at an angle of 25° approximately.

Thecæ.—Twenty-three to twenty in 1 inch (nine or eight in 1 cm.), and inclined to the polypary at an angle of 25° to 35°. Thecæ characterized by long and flexuous walls which bend inward so as to be almost at right angles to the virgula. Adult thecæ 3 mm. (·12 inch) long and $4\frac{1}{2}$ times as long as wide, overlapping for a third to a half of their length. Aperture concave, apparently oblique to the direction of the thecæ: it has a sharp denticle which is curved downward, but no spine. From Holm's figures it appears that the apertures are round or slightly oval.

Monograptus gotlandicus is allied to *M. dubius*

(1) In the character of its proximal extremity; and
(2) In the number of thecæ;

but is distinguished from it by

(1) The greater width of the polypary;
(2) The greater length of the thecæ, and the relative proportions of their length to their width.

The English form is sufficiently similar to the Swedish and Bohemian forms to make it clear that they are at any rate closely allied. The English graptolite appears to differ somewhat in the amount of overlap of its thecæ, this being greater than that measured by Holm (one-fifth), but not much more than appears from his figures. The angle of inclination of the thecæ is somewhat less, too, in the English specimens.

A specimen now in the Prague Museum from Colonie Krejci, of which I took a drawing in Bohemia, is very similar in shape to the English specimen.

Foreign Localities.—Bohemia (Koněprus and Colonie Krejci?); Gotland (*Pterygotus*-beds near Visby).

British Locality.—Only one specimen has been found hitherto, It was obtained by Prof. Watts from the Old Dingle Mill in the Long Mountain district, and is now in his collection.

Horizon.—Zone of *M. Nilssoni.*

Associates.—*M. Nilssoni* and *M. varians.*

Monograptus ultimus, Perner. (Pl. XXV, figs. 9 A & 9 B.)

1899. *Monograptus ultimus*, Perner, 'Études sur les Graptolites de Bohême' pt. iii, sect. *b*, pp. 13–14, text-figs. 14 *a–b* & pl. xvi, figs. 4, 5, 11 *a–b*.

The collection of graptolites from the Long Mountain, made by Prof. Watts, contains a few indifferently-preserved specimens of a small graptolite which is almost certainly the British representative of the Bohemian species *M. ultimus*, Perner. The English specimens are not sufficiently perfect for complete description, so that the following account is drawn mainly from Dr. Perner's original diagnosis and from my own drawings of some Bohemian specimens from Kosor presented to Prof. Lapworth by Dr. Perner. A few specimens of this species from the Lake District are to be found in the Natural History Museum, South Kensington.

Polypary never exceeding 2 cm. (·8 inch) in length, generally less than 1·27 cm. (·5 inch). Width at the proximal end = about ·63 mm. (·025 inch), increasing gradually to a maximum of 1·6 mm. (·06 inch).[1] Polypary slightly curved, especially at the proximal end.

Proximal Extremity.—Sicula long and curved, extending nearly to the level of the aperture of the second theca; about 1·9 mm. (·075 inch) long and 5 times as long as wide. Ventral wall of aperture prolonged into a spine. The first theca arises distinctly above the aperture of the sicula.

Fig. 13.—Monograptus ultimus (× 5). *Enlargement of fig. 9 B in Pl. XXV.*

Thecæ thirty to twenty-eight in the inch (twelve to eleven[2] in 1 cm.), inclined to the axis at an angle of 30° to 40°. In specimens in relief the thecæ are of the *M.-colonus* type, but Dr. Perner states that in compressed specimens they are rather of the type of *M. vomerinus* or *M. crenulatus.* Adult thecæ 1·6 mm. (·06 inch) long, and from 3 to 4 times as long as wide, in contact only or with slight overlap. Outer free wall straight or slightly concavo-convex. Dr. Perner states that the aperture is perpendicular to the axis of the polypary; but in all the Bohemian specimens preserved in relief in true profile, that I have examined, the aperture is at right angles to the axis of the theca: this is the case also with the English examples.

This species is readily distinguished by

(1) Its small size;
(2) Its narrowness;
(3) The number of thecæ to the inch; and
(4) The form of the thecæ.

The affinities of the species are by no means clear. I have placed it, however, in the group of *M. dubius* provisionally because

(1) It has only one type of thecæ; and
(2) The first theca is inclined to the sicula at a fairly low angle.

On the other hand, the thecæ possess characters which ally it to *M. vomerinus* and *M. colonus* rather than to *M. dubius*, and the relation of the first theca to the sicula is in some respects similar to that in *M. colonus.*

Foreign Localities.—Bohemia (Kosoř, Lochkov, Dlouhá Hora, Kozel, Dvoretz).

British Localities.—Long Mountain (north side, near Frochas); Lake District (Helm Knot).

Horizon.—Zone of *M. leintwardinensis* var. *incipiens.*

Associate.—*M. leintwardinensis* var. *incipiens.*

[1] Dr. Perner states the width at 2 mm., but no specimens figured measure more than 1·6 mm. [2] Dr. Perner says 'six,' but this is obviously a misprint.

(b) Group 2. Type *Monograptus colonus* (Barr.).

1. Two types of thecæ are present, the proximal thecæ possessing recurved apertures.
2. The outer wall of the first theca arises above the aperture of the sicula, and is inclined to it at a considerable angle (40° to 45°).
3. The length of the adult theca is, as a rule, 4 or more times the width.

Different species belonging to this group vary considerably in the form of the thecæ, but in all, the first two characteristics noted above are invariable.

Monograptus colonus (Barr.). (Pl. XXV, figs. 10 A–10 D and text-fig. 14, p. 464.)

1850. *Graptolithus colonus*, Barrande, 'Grapt. de Bohême' p. 42 & pl. ii, figs. 2–3.

There are probably few species that have been so frequently quoted by graptolithologists as this form, and few whose identification has been so uncertain. This is largely due to the fact that Barrande, under the name of *colonus*, figured three obviously different species (*op. cit.* pl. ii, figs. 1–5). Even when it became the general practice to regard Barrande's figs. 2 & 3 as the type-specimen, the difficulties of identification were by no means all removed, for doubt was still felt as to the accuracy of the figure. We now know that such doubts were well founded, for the artist's figure is not a reproduction of a complete specimen, but rather an inaccurate restoration in which the thecæ are drawn as if they were all of the form of those at the proximal extremity.

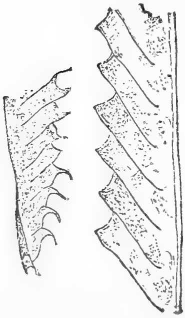
Fortunately there is now no room for doubt as to the true characters and form, not only of the proximal, but also of the distal thecæ of Barrande's original specimens on which he founded this species. Dr. Perner has refigured and redescribed these specimens, and through his kindness I was enabled to examine and draw them for myself. The following description, however, is drawn mainly from English specimens from the Lake District and from Builth, supplemented, where necessary, from these Bohemian forms.

Polypary.—3·8 to 5·8 cm. (1·5 to 2 inches) long, occasionally exceeding the latter limit. Straight distally, but possessing a distinct dorsal curvature in the proximal 6·3 mm. (·25 inch) or so of its length. Width at the proximal end = about ·84 mm. (·033 inch), exclusive of the apertural spine. Increase in width at the rate of about ·127 mm. (·005 inch) for each theca for the first six or eight thecæ, then much more gradual, and for the distal third or half of the length of the polypary the width is uniform. Maximum width = 2·3 mm. (·09 inch). Virgula slightly prolonged distally, rarely seen.

Proximal Extremity.—Sicula generally conspicuous, rather less than 1·9 mm. (·077 inch) long, and about ·32 mm. (·012 inch) wide at the aperture, so that it is 6 times as long as wide. Aperture provided with a long slender ventral spine. First theca

arising slightly above the aperture of the sicula, being inclined to it at an angle of about 45°. Sicula extending to the level of the second thecal aperture.

Fig. 14.—Monograptus colonus *(Barr.)*.



a b

a = proximal extremity, showing the sicula and the form of the proximal thecæ; from Vicarage Road, Builth. (×5.)

b = Distal thecæ of fig. 10 B in Pl. XXV, partly restored. (×5.)

Thecæ.—Thirty-two to twenty-six in the inch (twelve to ten in 1 cm.[1]), inclined to the axis at angles varying from 35° to 45°, generally about 40°. They are of two distinct types: the proximal four or five thecæ have their apertures strongly recurved, and possess a distinct spine which is bent downward. The succeeding thecæ have no such distinct spines, the apertures being concave, at right angles to the direction of the theca, and possessing only a somewhat pointed denticle to the lower apertural margin. According to Dr. Perner, in some Bohemian specimens preserved in full relief, the apertures are slightly convex and recurved in some of the more distal thecæ, but this character is not observed in ordinary compressed specimens preserved in shale. Proximal thecæ only $2\frac{1}{2}$ to 3 times as long as wide, the proportion gradually increasing until the adult thecæ are 4 times[2] (or even more) as long as wide. The amount of overlap varies from one quarter in the proximal thecæ to a third or a half in the adult thecæ. The length of an adult theca exceeds 2·6 mm. (·1 inch).

M. colonus has been almost universally quoted correctly as marking the horizon of the Lower Ludlow Shales in Britain and Europe. The species, however, as now defined, is by no means so common, in Britain at any rate, as has been generally supposed. In the Lower Ludlow Shales of Ludlow itself *M. colonus* is rare, and the only specimens that can be identified with it are those figured by Prof. Lapworth as *M. Rœmeri*: these are perhaps hardly typical, as I shall subsequently point out. Where the mudstone-facies of the Lower Ludlow is developed, as at Builth, *M. colonus* occurs in great abundance, and is one of the most characteristic graptolites of the *M.-Nilssoni* zone.

Although the foregoing description is significant of the typical form of *M. colonus* as found in Bohemia, yet in each British locality where this species occurs it is met with under certain slight variations; these local variations I do not, however, consider

[1] Dr. Perner reckons ten to eight in 1 cm., but this is undoubtedly a misprint.
[2] See Perner, 'Études sur les Graptolites de Bohême' pt. iii, sect. *b* (1899) pl. xiv, fig. 3.

to be worthy of varietal names. Helm Knot in Cumberland affords examples of *Monograptus colonus* (Pl. XXV, fig. 10 B) which, of all the British forms, bear the closest resemblance to the Bohemian type.

In the examples found at Adferton (Pl. XXV, fig. 10 D) in the Ludlow district (type-specimen *M. Rœmeri*, Lapw.), the polypary appears to widen out rather more rapidly than usual, and the adult thecæ are somewhat longer in proportion to their width, being 5 times as long as wide. At Builth, where the species occurs in great abundance, associated with *M. Nilssoni*, *M. bohemicus*, and *Retiolites spinosus*, it seems rarely to exceed 3·1 cm. (1·25 inch) in length, and the incurve at the proximal extremity is conspicuous. The thecæ are close-set, thirty-four to thirty in 1 inch (thirteen and a half to twelve in 1 cm.), and are long and narrow. Occasionally, however, at Builth (Pl. XXV, fig. 10 C), specimens differing but little from the typical form may be found. In the Long Mountain district the place of *M. colonus* is taken by another form, which I think is sufficiently distinct to be described as a new species.

Foreign Localities.—Bohemia (Vyskočilka, Kuchelbad, Kozel, Litohlav, Slavik, Butowitz, Borek, etc.; Colonies Krejci, Tachlowitz, d'Archiac, etc.); Scandinavia; Saxony; Thuringia; Harz Mountains; Polnisches Mittelgebirge; Graptolithengestein; France (Ardennes, Languedoc, Normandy, and Britanny).

British Localities.—Ludlow district (Elton Lane, Adferton); Builth (River Irfon, etc.); Lake District (Helm Knot, etc.); Dee Valley?

Horizon.—Zone of *M. Nilssoni*.

Associates.—*M. Nilssoni*, *M. bohemicus*, and *Retiolites spinosus*.

Var. LUDENSIS (Murch.). (Pl. XXV, fig. 11.)

1839. *Graptolithus ludensis*, Murchison, 'The Silurian System' p. 694 & pl. xxvi, fig. 2.

M. ludensis was originally figured by Murchison, but no description was appended. Beck, to whom Sir Roderick sent his specimens, identified them with Swedish forms which he intended to name *Graptolithus virgulatus*; but Murchison adhered to his own name of *Gr. ludensis*. M'Coy, in his 'British Palæozoic Fossils' (1855, p. 4), described *M. ludensis* in terms which make it evident that he was referring to *M. priodon*, and since that time *M. ludensis* has generally been considered as synonymous with *M. priodon*. Since the adoption of Bronn's earlier specific name *priodon*, the name *ludensis* has gradually disappeared from use.

It seemed clear, however, from Murchison's fig. 2, pl. xxvi, that his specimens did not belong to the *priodon*-group at all, and when I was enabled to examine and draw Murchison's original specimens in the Geological Society's Museum it was evident that they belonged to a form closely allied to *M. colonus*. Since the type-specimens were not well enough preserved to enable me to

make out all the characters, I went to Llanfair, and was fortunate enough to find the locality from which Murchison had evidently collected his type-specimens. Moreover, in addition to those which I myself collected, Dr. Humphreys, to whom my best thanks are due, kindly lent me a very fine slab crowded with examples.

All the Llanfair specimens are preserved in a hard calcareous sandstone which weathers deeply, and it is only on this weathered surface that the graptolites can be seen. Owing to this circumstance the apertures of the thecæ are generally imperfectly preserved, especially near the proximal end, where the apertures are somewhat turned underneath, and consequently half hidden from view. I have been unable, therefore, to determine with certainty whether the first thecæ are spinose: that is to say, whether they are identical in their characters with those of Barrande's *Monograptus colonus* or not. I believe that the first theca is spinose, but the succeeding thecæ are unprovided with spines. I have thought it best, therefore, to separate *M. ludensis* from *M. colonus* as a distinct variety. It agrees closely with *M. colonus* in general form and type of thecæ, but differs from it in the following particulars:—

(1) The proximal three or four thecæ are not recurved;
(2) The adult thecæ are 6 instead of 4 times as long as wide; and
(3) They overlap for a distance of more than one-half of their length.

Even if it were proved that one of the species included under Murchison's *Gr. ludensis* is identical with Barrande's *Gr. colonus*, I think that it would not be advisable, even for the sake of priority of nomenclature, to replace the well-known name of *colonus* by the old and unfamiliar designation *ludensis*: one, too, which was given with a most imperfect knowledge of the characters of the species, and was published without a description and with an inadequate drawing.

Locality.—Llanfair (Montgomeryshire).

Horizon.—Uncertain, but almost undoubtedly Lower Ludlow.

Associate.—*M. dubius*.

Var. COMPACTUS nov. (Pl. XXV, fig. 12.)

This well-marked variety agrees with the typical *M. colonus* in the shape of the thecæ and character of the proximal extremity, but is distinguished from it by the following characters:—

(1) Polypary dorsally curved throughout, and never exceeding 25·4 cm. (1 inch) in length;
(2) Maximum width of polypary attained about the thirteenth theca, the width decreasing towards both extremities;
(3) Virgula stout, and prolonged distally;
(4) There are forty-two to thirty-seven thecæ in 1 inch (sixteen and a half to fourteen and a half in 1 cm.); and
(5) The proximal thecæ are 3 times as long as wide, the adult $4\frac{1}{2}$ times as long as wide.

Only a few specimens of this form have been found, but the type is in an excellent state of preservation.

British Localities.—Ludlow district (Elton–Evenhay Lane, Elton Lane, and Stormer Hall); Abberley Hills?

Horizon.—Zone of *Monograptus Nilssoni.*

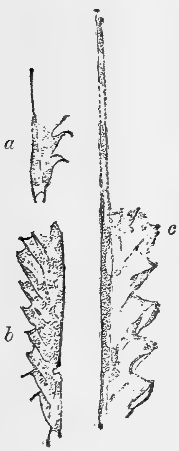
Associates.—*M. chimæra* var. *Salweyi*, *M. serra*, *M. varians* var. *pumilus*, and *M. Nilssoni.*

Monograptus varians, sp. nov. (Pl. XXV, figs. 14 A & 14 B.)

Polypary rarely exceeding 25·4 mm. (1 inch) in length, and generally only about 19 mm. (·75 inch) long. Straight distally, but with a distinct incurve at the proximal end. Width at proximal end = about ·76 mm. (·05 inch), the maximum width usually attained at the distal end being 1·77 mm. (·07 inch). Width increasing throughout the polypary, but most marked at the proximal end, where the rate of increase is approximately ·084 mm. (·003 inch) for each theca. Distal prolongation of the virgula very characteristic, being often as much as 12·7 mm. (·5 inch).

Proximal Extremity.—Sicula 1·77 mm. (·07 inch) long, and about ·32 mm. (·012 inch) wide, hence $5\frac{1}{2}$ times as long as wide. Its relation to the first theca is the same as in *M. colonus.* Apex of sicula slightly above the aperture of the second theca.

Fig. 15.—M. varians, *sp. nov.* ($\times 5$).



a & *b* = Proximal extremity, showing the sicula; from the road above Garbett's Hall.
c = Distal thecæ of the reverse side of fig. 14 A in Pl. XXV.

Thecæ.—Thirty-two to twenty-six in the inch (thirteen to ten in 1 cm.), inclined to the axis at an angle of 30° to 35° (in exact profile). Proximal three thecæ with distinct apertural spines, the remainder having a concave aperture of the usual type. Proximal thecæ about twice as long as wide, the adult thecæ from $3\frac{1}{2}$ to 4 times. Free for nearly three-quarters of their length, the outer and lower free wall being convex just below the aperture, and then becoming distinctly concave close to the aperture of the theca below, thus presenting the appearance of a marked excavation at that point. When preserved in true profile, this is not so conspicuous. The length of an adult theca is 2·2 mm. (·08 inch).

Localities. — Long Mountain (Lower Winnington, Dingle Mill, etc.); Montgomery Road; Ludlow district (Stormer Hall, etc.).

Horizon.—Zone of *M. Nilssoni.*

Associates.—*M. Nilssoni*, *M. dubius*, *M. uncinatus* var. *orbatus*, *Retiolites spinosus*, *M. crinitus*, and *M. chimæra* var. *Salweyi.*

Affinities, etc.—At first sight this form appears to be closely

allied to *Monograptus colonus*, but on examination it presents so many differences that I am of opinion that it should be regarded as a distinct species rather than merely as a variety of that form. It differs from *M. colonus* in the following particulars:—

(1) The polypary is shorter and narrower;
(2) Width of the polypary increasing more uniformly throughout;
(3) Distal prolongation of the virgula more persistent and conspicuous;
(4) The thecæ present a smaller amount of overlap; and
(5) The excavation at the base of the free part of the theca is peculiar.

It agrees with *M. colonus* in general form, and in possessing two types of thecæ; and it occurs in abundance at the same horizon as that at which one would expect to find *M. colonus* in the Long Mountain district.

M. varians is remarkable in presenting certain variations even in the same limited area, and, so far as can be judged, at the same horizon. It occurs at several localities in large numbers, in association with *M. Nilssoni*, on the north side of the Long Mountain; at the easternmost locality, namely at Winnington Green, it is usually only 12·7 to 19 mm. (·5 to ·75 inch) long, and the first two thecæ are spinose. At the Old Dingle Mill, 1½ miles farther west, it occurs also in great abundance in association with *M. Nilssoni*, but is longer, and the first theca alone is spinose. Some 2½ miles still farther west, above Garbett's Hall, it is still long, but has the first two thecæ spinose. These variations are quite constant for each locality. Between Winnington Green and Old Dingle Mill in the Trefnant–Middletown Brook *M. varians* occurs in association with *Retiolites spinosus* and *M. Nilssoni*, but is broader and coarser-looking, and the first three thecæ possess strong spines. As already mentioned in the first part of this paper, it is uncertain whether these graptolites occur here at a higher horizon than usual. The foregoing facts are interesting, as showing how readily small variations may take place even within so limited an area.

Var. *a* nov. (Pl. XXV, figs. 16 A & 16 B.)

1880. *Monograptus colonus* (Barr.) Lapworth, Ann. & Mag. Nat. Hist. ser. 5, vol. v, p. 152 & pl. iv, figs. 3 *b*–3 *d*.

This form was figured by Prof. Lapworth from a specimen found at Mary Knoll, Ludlow, and belonging to Mr. Hopkinson, as *M. colonus* (Barr.). Other examples have been collected by me from Stormer Hall, and I regard it as a variety of *M. varians*. It resembles the typical *M. varians* in

(1) The form of the thecæ;
(2) The long distally-produced virgula; and
(3) The character of the proximal extremity.

It differs from it in:—

(1) Its greater width of 2·1 mm. (·08 inch), which is attained more rapidly in *M. varians*;
(2) Its higher angle of inclination of the thecæ, namely 40°; and
(3) The greater number of thecæ in the inch (thirty-five to twenty-eight).

Horizon.—Zone of *M. Nilssoni*.

Associates.—*M. Nilssoni*, *M. chimæra* var. *Salweyi*, and *M. dubius*.

Var. β nov. (Pl. XXV, fig. 15.)

A second variety found in the Ludlow district is of interest as forming a connecting-link between the typical *Monograptus varians* and the variety next to be described, namely, *M. varians* var. *pumilus* nov. It agrees with *M. varians* in

(1) The general form of the polypary; and
(2) The shape of the thecæ.

It is distinguished from *M. varians* by the following characters:—

(1) The polypary is rather longer;
(2) The sicula is intermediate in length between that of *M. varians* and its variety *pumilus*, and extends midway between the apertures of the second and third thecæ.
(3) There are from thirty-six to thirty thecæ in the inch (fourteen to twelve in 1 cm.).

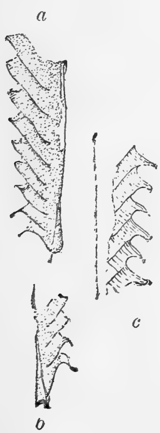
Locality.—Ludlow district (Elton Lane).
Horizon.—Zone of *M. Nilssoni.*
Associates.—*M. varians* var. *pumilus*, *M. Nilssoni*, and *M. dubius.*

Var. PUMILUS nov. (Pl. XXV, figs. 17 A & 17 B.)

This variety agrees with the typical *M. varians* in the shape of the thecæ. It is readily distinguished from it by the following characters:—

(1) Polypary seldom attaining a greater length than 12·7 mm. (·5 inch);
(2) Polypary straight, except for a very slight dorsal curvature;
(3) Sicula 1·9 mm. (·075 inch) in length and ·32 mm. (·012 inch) wide, hence 6 times as long as wide, extending to nearly the level of the aperture of the third theca. Dorsal wall of sicula very straight;
(4) There are forty-two to thirty-six thecæ in 1 inch (sixteen and a half to fourteen and a half in 1 cm.); and
(5) The thecal growth-lines are well marked.

Fig. 16.—M. varians *var.* pumilus *nov.* ($\times 5$).



a=Proximal extremity; from the Abberley Hills, coll. Wickham King.
b=Proximal extremity; from Elton Lane.
c=Cast of distal thecæ, showing growth-lines. From Round Hill, Abberley; coll. Wickham King.

British Localities.— Ludlow district (Elton Lane, Elton-Evenhay Lane, Stormer Hall); Abberley Hills. It occurs in great abundance at these localities.

Horizon.—Zones of *M. Nilssoni* and *M. scanicus.*

Associates.—*M. Nilssoni*, *M. colonus* var. *compactus*, *M. dubius*, *M. varians* var. β, *M. scanicus*, *M. chimæra* and its variety *Salweyi.*

Monograptus Rœmeri (Barr.). (Pl. XXV, figs. 13 A & 13 B.)

1850. *Graptolithus Rœmeri*, Barrande, 'Grapt. de Bohême' p. 41 & pl. ii, figs. 9–11.

Polypary.—3·8 to 7·3 cm. (1·5 to 2·5 inches) long, with a characteristic form, the dorsal margin being slightly convex at the proximal extremity, then concave for the greater part of its length, and again convex at the distal end. The width at the first theca is ·89 mm. (·035 inch), increasing for the first four thecæ at the rate of ·19 mm. (·0075 inch). After that increase it is more gradual, the maximum width, 2·9 mm. (·115 inch), being attained at about the fourteenth theca. Some examples, however, measure as much as 3·6 to 4·2 mm. (·14 to ·17 inch). Frequently the polypary appears to narrow towards the distal end. Distal prolongation of virgula short, and rarely seen in British specimens, but it may be as long as 2 cm. in Bohemian forms.

Proximal Extremity.—Sicula about 1·8 mm. (·07 inch) long, and ·32 mm. (·012 inch) wide, hence more than 5 times as long as wide, and extending to about the apertures of the second theca. Aperture provided with a long ventral spine. First theca the same as in *M. colonus*.

Fig. 17.—M. Rœmeri (*Barr.*) × 5.

[Proximal extremity, showing the sicula: enlargement of the reverse side of fig. 13 A in Pl. XXV.]

Thecæ.—Thirty-four to twenty-eight in the inch (thirteen and a half to eleven in 1 cm.), inclined to the axis at an angle of 40° to 45°. Thecæ long, narrow tubes, the adult thecæ being 5 or $5\frac{1}{2}$ times as long as wide, and overlapping for two-thirds of their length. Aperture wide and concave (somewhat convex in relief) and at right angles to the direction of the theca. Proximal three or four thecæ only about 3 times as long as wide, inclined to the axis at a high angle, overlapping for half their length, and with the aperture recurved.

M. Rœmeri is a well-marked species characterized by (1) its peculiar double curvature, (2) its rapid increase in width, and (3) the amount of thecal overlap. This species has not been correctly identified in England hitherto, owing probably to its rarity. It does not seem to have been yet recognized in Sweden, unless Tullberg's *M. colonus*[1] is referable to it, but Dr. Barrois records it from France, and an isolated specimen was figured by Heidenhain from the Graptolithengestein. Nowhere, however, does it occur so abundantly and characteristically as in Bohemia. This species is quite distinct from *M. colonus*, though Prof. Frech seems to regard its separation from *M. colonus* as 'at least doubtful.'

Foreign Localities.—Bohemia (Butowitz, Borek, Slavik, etc.), Graptolithengestein; France (Languedoc, Britanny, etc.); Scania? (Knashufvud).

[1] 'Skånes Graptoliter' pt. ii (1883) Sver. Geol. Undersökn. ser. C, no. 55, pl. i, fig. 21.

British Localities.—Ludlow district (Elton Lane, Elton–Ludlow Road ?; Adferton ?; Dudley (Sedgley Shales); Long Mountain (Trefnant–Middletown Brook); Builth (Aberedw Hill).

Horizon.—In Bohemia it occurs in the Limestone E*e* 2, and belongs, therefore, characteristically to the Lower Ludlow. In Britain it is found in the zones of *Monograptus Nilssoni* and *M. scanicus*, characteristically in the latter.

Associates.—*M. scanicus*, *M. chimæra*, and *M. Nilssoni*.

(c) Group 3. Type *M. chimæra* (Barr.).

1. Proximal extremity of the form of that of the *M.-colonus* type.
2. Thecal apertures provided with long spines.

Monograptus chimæra (Barr.). (Pl. XXV, figs. 18 A–18 D.)

1850. *Graptolithus chimæra*, Barrande, 'Graptolites de Bohême' p. 52 & pl. iv, figs. 34–35.

Polypary.—2·54 to 3·8 cm. (1 to 1·5 inch) long, straight distally, but with a distinct dorsal curvature for the first 5 mm. (·2 inch) of its length. Increase in width most rapid for the first five or six thecæ, but generally slight throughout the whole length. Width at the aperture of the first theca (exclusive of spines) = generally about ·89 mm. (·035 inch), while the maximum width of the distal end (exclusive of spines) is 1·9 mm. (·075 inch). Virgula produced slightly beyond the distal end.

Proximal Extremity.—Sicula approximately 1·7 mm. (·066 inch) long, extending to about midway between the apertures of the second and third thecæ. Width at the aperture = ·34 mm. (·013 inch), hence the sicula is approximately 5 times as long as wide.

Thecæ.—Thirty-two to twenty-eight in the inch (thirteen to eleven in 1 cm.), inclined to the axis at an angle of about 40° to 50°. Straight broad tubes, fairly uniform in width throughout, provided with a stout blunt spine arising from the aperture. This spine has a maximum length of ·63 mm. (·025 inch), and arises slightly above the centre of the lateral wall of the aperture, though the apparent position varies considerably in compressed specimens. The proximal thecæ are twice, and the distal thecæ 4 times as long as wide. The amount of overlap is about half of the whole length.

I have referred this species provisionally to *M. chimæra* (Barr.), since the type of thecæ and position of the spine are similar in the Bohemian and British forms. The Bohemian type-specimen, however, is small, only 12·7 mm. (·5 inch) long, and is not well preserved, and possibly a further study of more perfect specimens may prove that the British form is a variety of it. No other species resembles this closely, except *M. Salweyi* (Hopk.) and *M. colonus*, Jækel, and its affinities to these will be considered later. Numerous small specimens occur in association with the adult forms at the Elton-Ludlow Road locality (Pl. XXV, fig. 18 D), which differ somewhat in their general shape, but they may be only young forms, and are not worthy of a varietal distinction.

I have examined a large number of specimens in the hope of

detecting the true form of the theca and the position of the apertural spine, but the English examples are so indifferently preserved that it is only possible to infer their characters. When the thecæ are preserved in true profile, the spine arises slightly above the centre of the lateral wall of the aperture, and is not a prolongation of the interthecal wall (see fig. 18 *a*, p. 473), as is the case in *Monograptus leintwardinensis*. This, then, would probably be the true position of the spine if the theca were in relief, and might produce a certain angularity in the form of the theca; indeed, in one specimen, preserved so that the apertures face the observer, one or two of the thecæ appeared to be hexagonal in shape. The spines of the proximal three or four thecæ are seldom seen in true profile, and present much the same appearance as those of *M. colonus*; but it is probable that there is no essential difference between their original position in the proximal and that in the distal parts of the polypary. The various positions that the spine assumes under different conditions of preservation may be best seen from the figures.

Foreign Localities.—Bohemia (Hinter-Kopanina). (E*e* 2.)

British Localities.—Ludlow district (Elton-Ludlow Road, Elton Lane); Builth district (Aberedw Hill); the Long Mountain (north side).

Horizon.—It occurs typically in the *M.-scanicus* zone, but is also found in the *M.-Nilssoni* zone.

Associates.—*M. scanicus, M. Rœmeri, M. dubius, M. bohemicus,* and *M. Nilssoni.*

Var. *Salweyi* (Hopk. MS.). (Pl. XXV, figs. 19 A & 19 B and text-fig. 18, p. 473.)

1880. *Monograptus Salweyi* (Hopk. MS.) Lapworth, Ann. & Mag. Nat. Hist. ser. 5, vol. v, p. 150 & pl. iv, figs. 2 *a–b*.

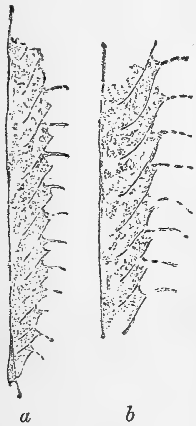
M. chimæra var. *Salweyi* was originally named by Mr. Hopkinson as a distinct species, and his type-specimen, which shows the distal end only, was figured by Prof. Lapworth. From numerous specimens of this form, collected by me from Mr. Hopkinson's type-locality of Stormer Hall, near Leintwardine, I have been able to complete the description of the whole polypary.

Although no other specimen was found showing the extremely long distal prolongation of the virgula, so characteristic of Mr. Hopkinson's type-specimen, there is no doubt as to its identity, for it is the dominant species at this locality. *M. Salweyi* in its typical form is a well-marked variety of *M. chimæra* (Barr.), and is distinguished from it by the following peculiarities:—

(1) Polypary seldom exceeding 12·7 mm. (·5 inch) in length, and attaining a maximum width of 1·6 mm. (·06 inch);
(2) Margins of polypary parallel except at the proximal extremity, the increase in width taking place within the length occupied by the first five or six thecæ;
(3) Polypary straight throughout;
(4) Virgula prolonged distally for a considerable length; and
(5) Thecal apertural spines longer and more slender.

But although the extreme forms of *Monograptus chimæra* and *M. Salweyi* are readily distinguished, there are so many intermediate shapes linking the two together that it is often impossible to separate them.

Fig. 18.—M. chimæra, *var.* Salweyi *(Hopk.) from Stormer Hall (×5).*



a=Complete specimen, showing sicula.
b=Distal thecæ, with long curved spines.

The only other *Monograptus* with which this variety *Salweyi* can be confused is *M. colonus*, Jækel. That form belongs undoubtedly to the group of *M. chimæra*, but whether it should be referred to *M. chimæra* or to its variety *Salweyi* is uncertain. One fragment found at the Stormer Hall locality, if referable to that variety, must have been of abnormal size. It is 25·4 mm. (1 inch) long, and about 2·1 mm. (·08 inch) wide, while the virgula, which is extremely broad, is produced distally for 10 mm. (·4 inch). The entire polypary, however, is not preserved, and consequently its identification with *M. chimæra* var. *Salweyi* is doubtful.

Prof. Frech identifies [1] *M. uncinatus*, Tullb., with *M. Salweyi*, but he himself figures (*op. cit.* fig. 213) as an example of *M. uncinatus* a fragment from Djurröd (Scania), which in my opinion belongs to *M. leintwardinensis.* I have been unable to examine Tullberg's types, but I have found his drawings, as respects other species, so accurate that I have no reason to regard them in this case as incorrect.

Foreign Localities.—Unknown abroad unless *M. colonus*, Jækel, may be referred to it, and this occurs in the Graptolithengestein of the German Drift.

British Localities.—It occurs in abundance at Stormer Hall near Leintwardine; it has also been found at Elton–Evenhay Lane, and at Llettygynfach, south-west of the Long Mountain.

Horizon.—Zone of *M. Nilssoni*.

Associates.—*M. dubius*, *M. colonus* var. *compactus*, and *M. varians* var. *a*.

Var. *a* nov. (Pl. XXV, fig. 20.)

This interesting form, although undoubtedly a variety of *M. chimæra,* presents peculiarities at various stages of its growth which give parts of the polypary a remarkable resemblance to *M. colonus*, or at any rate to species belonging to that group.

[1] 'Lethæa Geognostica' vol. i, pt. iii (1897) p. 658.

It agrees with the typical *Monograptus chimæra* in :—

(1) The character of the proximal extremity;
(2) The spinose nature of some of the thecæ; and
(3) The number of thecæ to the inch.

It is distinguished by the following peculiarities :—

(1) The form of the polypary is that of a broad *M. colonus.* Length =2·54 to 3·8 cm. (1 to 1·5 inch), and the maximum width of 2·5 mm. (·1 inch) is attained rapidly;
(2) All the thecæ, except the first six or seven, either have very short blunt spines, or are destitute of them altogether.

The foregoing description is based partly on British specimens and partly on Swedish forms in the possession of Prof. Lapworth, the latter being better preserved and agreeing with the British forms in most particulars.

Localities.—Ludlow district (Elton Lane, Elton-Ludlow Road).

Horizon.—Zone of *M. scanicus.*

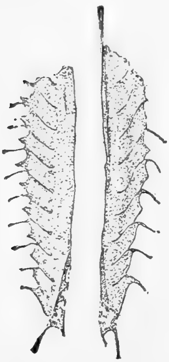
Associates.—*M. varians* var. *pumilus* and *M. scanicus.*

MONOGRAPTUS LEINTWARDINENSIS, Hopk. MS. (Pl. XXV, figs. 21 A & 21 B.)

1880. *Monograptus leintwardinensis,* Hopk. MS. Lapworth, Ann. & Mag. Nat. Hist. ser. 5, vol. v, p. 149 & pl. iv, figs. 1 *a*–1 *d.*

Polypary short, seldom exceeding 12·7 mm. (·5 inch) in length. Straight distally, with a slight curvature at the proximal end. Width at the aperture of the first theca (exclusive of spine) = about ·85 to 1 mm. (·03 to ·04 inch). Increase in width gradual for the first five or six thecæ, until the maximum width of 1·6 mm. (·06 inch) is attained. Virgula generally produced somewhat beyond the distal end of the polypary.

Fig. 19.—M. leintwardinensis, *Hopk., from Church Hill Quarry (×5).*



a=Enlargement of fig. 21 A in Pl. XXV.
b=Specimen showing different positions of the thecal spines.

Proximal Extremity. — Sicula conspicuous, long, and narrow. About 2·1 mm. (·08 inch) in length, extending to midway between the apertures of the second and third thecæ. Width at the aperture =·38 mm. (·015 inch), so that the length is almost 6 times the width. Aperture provided with a long ventral spine, and a shorter incurved dorsal one. The sicula gives origin to the first theca at a distance of about one-fifth of its length above the aperture.

Thecæ.—Fourteen to eleven in the whole polypary, giving an average of thirty-eight to thirty-six thecæ in the inch (fifteen to fourteen in 1 cm.). Fairly short and narrow

tubes, adult ones 1·7 mm. (·07 inch) in length and 3½ times as long as wide. At the proximal end the thecæ are merely in contact; distally they overlap for not quite half their length. They are inclined to the axis at an angle of 35° to 45°. Outer free wall rather deeply excavated just above the aperture of the theca below, then expanding somewhat, and again contracting slightly at the aperture, which is markedly concave. The upper interthecal wall of each theca is continued as a long flexible spine ·63 mm. (·025 inch) long, generally curving slightly over the aperture.

This species is very characteristic of the Lower Ludlow, and is readily recognized by its (*a*) small size, (*b*) thecal spines, and (*c*) gregarious habit, occurring as it does in great numbers on a slab unassociated with other species. As in all other spinose forms, the position of the spine varies considerably under different conditions of preservation. In forms preserved in perfect profile it is clear that the spine arises from the upper interthecal wall. In compressed forms it seems to arise some little distance up the outer wall of the theca next above, but this appearance is deceptive. Sometimes the aperture appears very narrow, and then the position of the spine does not differ in any way from that of the spine of *Monograptus chimæra* var. *Salweyi* in a similar aspect.

M. leintwardinensis has not been described from abroad, but, as was pointed out on p. 473, Prof. Frech's figure of *M. uncinatus* from Scania may be that of a Swedish form referable to this species.

Foreign Localities.—Djurröd in Scania?

British Localities.—Ludlow district (Leintwardine, Church Hill, Adferton? Trippleton? Aymestry, Vinnall); Broxton and Burton; Long Mountain (Llettygynfach); Builth district (Aberedw); Presteign, Old Radnor; Dee Valley (Llantisilio Road and Pen-y-Vivod); Lake District?

Horizon.—*M. leintwardinensis* is the characteristic zone-fossil of the highest beds of the Lower Ludlow, and ranges up into the Aymestry Limestone.

Associates.—It has not yet been found in association with any other graptolite.

Var. INCIPIENS, nov. (Pl. XXV, figs. 22 A & 22 B.)

This variety agrees with the typical *M. leintwardinensis* in

(1) The presence of the typical apertural spines in some of the thecæ; and
(2) The number of thecæ to the inch.

It is distinguished from it by the following peculiarities:—

(1) Polypary wider, the maximum width being 2 to 2·3 mm. (·08 to ·09 inch) and somewhat longer;
(2) Sicula broader, being ·42 mm. (·016 inch) in diameter, and rarely more than 4½ times as long as wide;
(3) The proximal thecæ are provided with spines similar to those of *M. leintwardinensis*, but the distal thecæ have no spines, and are at least 4 times as long as wide; and
(4) The adult thecæ overlap for a half to three quarters of their length.

This form is abundant in certain localities, and may be merely a local variety of the typical *Monograptus leintwardinensis*, the two not being found in association. It seems to occur at a somewhat lower horizon, and may possibly represent the form from which *M. leintwardinensis* was eventually developed.

The form figured by Dr. Perner[1] as *Monograptus* sp. from Hvižďalka is probably referable to this variety.

British Localities.—Montgomery Road; Long Mountain (various localities, such as Rose & Crown Inn, Lower Winnington, etc.); Lake District (Tebay Gill, Bannisdale).

Horizon.—Near the top of the Lower Ludlow Beds.

Associate.—*M. ultimus*.

(d) Group 4. Type *M. uncinatus*, Tullb.

1. Thecæ short broad tubes; apertures circular, upper wall prolonged into a spinose claw.
2. Polypary of the general type of *M. colonus*.

The typical Swedish form *M. uncinatus* has not hitherto been found in Britain, but the group which it typifies is represented by two varieties.

Monograptus uncinatus var. *orbatus* nov. (Pl. XXV, figs. 23A & 23B.)

Polypary from 2·54 to 5·08 cm. (1 to 2 inches) long, and increasing gradually from a width of ·76 mm. (·03 inch) at the proximal end to a maximum width of 1·9 mm. (·08 inch) at the distal end, the increase being at the rate of about ·13 mm. (·025 inch) for each theca; somewhat irregularly curved, the dorsal margin of the proximal third convex, then distinctly concave, and finally in the distal third of its length becoming straight or slightly convex. This 'broken-back' appearance (Pl. XXV, fig. 23A), though less marked in some specimens than in others, is characteristic, and reminds one of *M. riccartonensis*, Lapw. Virgula slightly produced distally.

Fig. 20.—M. uncinatus *var.* orbatus *nov.*

a *b*

a=Proximal extremity, showing sicula; from Trefnant-Middletown Brook.
b=Distal thecæ, from Dudley; coll. Dr. Fraser.

Proximal Extremity.—Sicula = about 1·6 mm. (·06 inch) in length, and ·32 mm. (·012 inch) wide at the aperture, hence it is five times as long as wide. Outer wall of sicula convex, especially near the aperture, and with a short spine. The first theca arises from the sicula above the aperture, being inclined to it at an angle of 30°. The

[1] 'Études sur les Graptolites de Bohême' pt. iii, sect. *b* (1899) pl. xvii, fig. 14.

sicula appears to extend to about the level of the aperture of the second theca.

Thecæ.—Thirty to twenty-four in the inch (twelve to nine in 1 cm.), inclined to the axis at an angle of 30° to 35°. Original shape of the thecæ somewhat difficult to determine, as it varies considerably in different aspects. In some views the thecal aperture appears to be circular, as in *Monograptus vomerinus*, and the upper wall is prolonged into a long curved spine (text-fig. 20 *b*, p. 476). In other views the aperture is not so well seen, the upper thecal wall curving over it as a short claw which is prolonged into a spine directed downward, reminding one of *M. riccartonensis*, Lapw. (text-fig. 20 *a*). There are also appearances intermediate between these extremes. The various aspects of the thecæ are shown in the figures. Lobe-like projections of the thecæ occupy only about a quarter of the total width of the polypary. The adult thecæ are about 1·27 mm. (·05 inch) long, rather more than ·63 mm. (·025 inch) wide, being therefore barely twice as long as wide. Thecæ in contact only, or with slight overlap.

The occurrence of *M. uncinatus* var. *orbatus* in the Lower Ludlow Shales is of particular interest, since the variety forms a connecting-link between the graptolitic fauna of the Wenlock and Ludlow. It combines some of the characters of the *M.-colonus* group, so characteristic of the Ludlow, with some of those of the *M.-priodon* and *M.-vomerinus* groups of the Wenlock, for it resembles the former (1) in its general shape, (2) in the character of the proximal extremity, and (3) in the distally-produced virgula, while it is allied to the latter in the shape and form of the thecæ.

It may be readily distinguished from all other Ludlow graptolites, except those of the group of *M. uncinatus*, by:—

(1) The generally irregular form of the polypary; and
(2) The character of the thecæ.

It is undoubtedly closely allied to *M. uncinatus*, Tullb., of which it must be regarded as a variety. The English form may be distinguished from the Swedish species by:—

(1) Its irregular form (*M. uncinatus* is nearly straight);
(2) The form of the sicula;
(3) The larger number of thecæ to the inch (thirty as against twenty-four);
(4) The spinose termination of the apertural claw of the theca.

Localities.—Long Mountain (Trefnant–Middletown Brook).

Horizon.—Zone of *M. Nilssoni*.

Associates.—*M. bohemicus*, *M. Nilssoni*, *M. vulgaris* var. *a*, and *M. varians*.

Var. MICROPOMA (Jækel). (Pl. XXV, figs. 24 A & 24 B and text-fig. 21, p. 478.)

1889. *Pomatograptus micropoma*, Jækel, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xli, pl. xxix, figs. 4–6.

I have found only a few British specimens of this form, and these are somewhat indifferently preserved. I have no doubt, however,

that the thecæ are of the same type as those of *Monograptus uncinatus*, and that this should be regarded as a variety of the species distinguished by the following peculiarities :—

(1) Polypary almost straight, except for a slight dorsal curve at the proximal end;
(2) Maximum width of 1·27 mm. (·05 inch) attained very gradually and uniformly;
(3) Thecæ twenty-six to twenty-two in the inch (ten to nine in 1 cm.);
(4) Apertural claw shorter and narrower, and form of theca resembling that of *M. vomerinus* more closely than it does that of *M. riccartonensis.*

Fig. 21.—M. uncinatus, *var.* micropoma *(Jækel)* ×*5.*

a=Proximal extremity, with sicula; from Elton-Ludlow Road.
b=Distal thecæ; from Stormer Hall.

The above characters will serve to distinguish it from *M. uncinatus* var. *orbatus.*

I believe that the English form is identical with Jækel's species *micropoma*, though I have been unable, on account of the scarcity of specimens and the consequent lack of good material, to investigate all those structural details necessary for a thoroughly satisfactory identification. The German specimens appear to be in a better state of preservation than the English examples, and Jækel considers that the apertural spine is rather of the nature of a lobe than a spine proper. This view coincides with my own opinion. Jækel holds that his species is identical with *Monograptus* sp. of Heidenhain, and I have therefore used Heidenhain's description to supplement his own.

The English and German specimens of this variety agree in the following characters :—

(1) The general form of the polypary;
(2) The number of thecæ to the inch;
(3) The general shape of the thecæ and the nature of the aperture.

The angle of inclination of the thecæ to the axis is greater in the German specimens (45° against 25° to 30°), but this may be due merely to the conditions of preservation; indeed, in the proximal part of fig. 5 of Jækel, the angle of inclination is only 30°. The spine in Jækel's figures is shorter than in the English specimens.

Foreign Localities.—Graptolithengestein at Kunzendorf; doubtfully from Röstånga in Scania.

British Localities.—Ludlow district (Elton Lane, Elton-Ludlow Road, and Stormer Hall); Long Mountain (Lower Winnington and Garbett's Hall).

Horizon.—In England this variety occurs in the zones of

Monograptus Nilssoni and *M. scanicus*, more especially in the former. In Germany it is found in the Graptolithengestein, in association with other Lower Ludlow forms.

Associates.—*M. bohemicus, M. Nilssoni, M. varians* and its variety *pumilus, M. dubius,* and *M. chimæra* var. *Salweyi.*

(e) Group 5. Type *M.* SCANICUS, Tullb.

1. Thecæ without overlap; apertures concave, with the upper wall bent into a claw.
2. Polypary slender, curved.

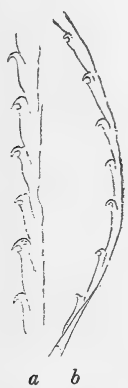
MONOGRAPTUS SCANICUS, Tullb. (Pl. XXV, figs. 25 A & 25 B.)

1883. 'Skånes Graptoliter' pt. ii, Sver. Geol. Undersökn. ser. C, no. 55, p. 26 & pl. ii, fig. 38.

Polypary slender, slightly curved, very flexible, so that the general form varies constantly. Length of whole polypary not seen; the longest fragments measure 10·1 cm. (4 inches). It is extremely slender at the proximal end, about ·254 mm. (·01 inch) in width, widening very gradually, and attaining a maximum width of about 1 mm. (·04 inch) at the distal end.

Proximal Extremity.—Sicula rarely preserved, but it has been seen in a few specimens; about 1·5 mm. (·06 inch) in length, while the width at the aperture is about one-sixth to one-seventh of the length. Aperture concave, dorsal wall provided with a fairly long, slender spine. The first theca arises at a distance of about one-third of the length of the sicula from the aperture of the sicula.

Fig. 22.—M. scanicus, *Tullb., from Aberedw Hill (×5).*



a=Distal thecæ.
b=Proximal extremity, with sicula.

Thecæ.—Twenty to twenty-three in the inch (eight to nine in 10 mm.), being more distant at the proximal extremity and inclined to the axis at an angle of 10° to 20°; generally arranged on the concave side of the polypary, though occasionally at the proximal extremity they occur on the convex side. Thecæ long narrow tubes, of equal width throughout; aperture concave, the upper wall curving over it in the form of a claw, which is bent outward and downward. The aperture resembles that of *M. uncinatus* in shape, but differs markedly in size. At the proximal extremity the proportion between the length and width of the thecæ is about 7 to 1; distally it is only 5 to 1. Thecæ in contact merely, no overlap; the median wall of the proximal thecæ is much shorter than that of the more distal thecæ.

The curves of the polypary vary greatly in different fragments, some showing the proximal extremity with a double curvature like that of *Monograptus Nilssoni*, while others are concavely curved throughout and bear the thecæ on the concave side. The more distal fragments are first gently curved, and finally straight. Perfectly straight fragments 7·6 cm. (3 inches) long have been found, showing that the complete polypary was probably some 12·7 to 15·2 cm. (5 to 6 inches) long.

Affinities.—This form is clearly identical with Tullberg's Swedish species, and although it has never previously been described and figured in England, it was recorded by Prof. Lapworth as early as 1880.[1] It is a very clearly defined species, and there is little difficulty in its correct identification. Jækel's *Pomatograptus Becki* is most probably referable to this species, and he himself says that it is known as *M. scanicus* in Sweden. Prof. Frech's view [2] that Jækel's species is referable rather to *M. cygneus*, Törnq., which he regards as a synonym of *M. scanicus* conditioned by stratigraphical differences only, may here be mentioned.

Foreign Localities.—Sweden (Knashufvud, Ask, Röfvarekulan, Djurröd, and many places in South-eastern Scania); Graptolithengestein (Brandenburg, Rostock, Königsberg, etc.); Polnisches Mittelgebirge; Northern France.

British Localities.—Ludlow district (Elton Lane, Elton-Evenhay Lane, Elton-Ludlow Road, etc.); Builth (Aberedw Hill); Abberley Hills; Long Mountain?

Horizon.—In Britain *M. scanicus* occurs in the *M.-Nilssoni* and *M.-scanicus* zones. In Sweden it is found in the *Cardiola*-Skiffer, and in France in beds containing *Cardiola interrupta*.

Associates.—*M. bohemicus*, *M. Nilssoni*, *M. dubius*, *M. chimæra* and its var. *α*, *M. Rœmeri*, and *M. varians* var. *pumilus*, etc.

Monograptus crinitus, sp. nov. (Pl. XXV, figs. 26 A & 26 B and text-fig. 23, p. 481.)

Polypary probably reached many inches in length, but is only preserved in a fragmentary condition, some of the fragments, however, being 5 to 7·5 cm. (2 to 3 inches) long. Occurs covering the surface of the rock like a thick mass of hairs. Maximum width of the hair-like polypary, even at the aperture of the theca = only ·38 mm. (·015 inch), while it may be as little as ·19 mm. (·007 inch). Between the apertures of the thecæ the width is considerably less. Polypary curved in various directions, some fragments being nearly straight, others concavely curved ventrally; but as a rule there is a distinct convex curvature, the thecæ occurring on the concave side.

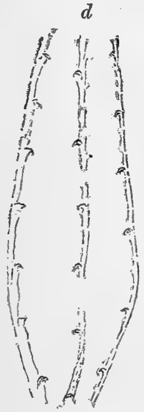
Proximal Extremity.—The polypary becomes so extremely slender at the proximal extremity that it is very difficult to identify the sicula with certainty; it appears, however, to be similar to

[1] 'Geological Distribution of the Rhabdophora' Ann. & Mag. Nat. Hist. ser. 5, vol. v, p. 369.

[2] 'Lethæa Geognostica' vol. i, pt. iii (1897) p. 644.

that of *M. scanicus,* as is also its relation to the first theca. It is about 1·4 mm. (·055 inch) long, and 6 or $6\frac{1}{2}$ times as long as wide Aperture concave, with spines. The first theca arises at a distance of from a half to a third of the length of the sicula from the aperture of the sicula.

Fig. 23. — Monograptus crinitus, *sp. nov., from Lower Winnington Lane, Long Mountain* (×5).



a=Enlargement of fig. 26 A in Pl. XXV.
b=Proximal extremity.
c, d=More distal thecæ.

Thecæ.—Fourteen to eighteen in the inch (five and a half to seven in 1 cm.), inclined to the axis at an angle of 5° to 10°. Long narrow tubes, expanding gradually towards the aperture, the upper wall of which bends over like a small hook or claw. In the distal thecæ this claw-like portion is blunter and less hook-like. Length of proximal thecæ=1·9 mm. (·063 inch), whereas that of the more distal is 1·6 mm. (·055 inch). Thecæ in contact only.

Affinities, etc. — This species seems to be quite distinct from any other Lower Ludlow graptolite yet described. It may be readily distinguished by:—

(1) Its delicate thread-like form;
(2) The hook-like shape of the thecæ; and
(3) The distance apart of the thecæ.

It is a matter of considerable difficulty to distinguish species with such very slender forms one from the other, owing to the impossibility of making out the necessary minute details; hence the general form of the polypary in these cases must be the main guide. It is mainly on this ground that I consider this species distinct from *M. Barrandei* (Suess), though it resembles that species in its slender shape and number of thecæ to the inch. *M. Barrandei,* however, is straight or very slightly curved distally, while *M. crinitus* is markedly flexuous and curved throughout. The type of theca, too, is rather different in the two forms, so far as one can judge in such minute cells: the apertures in *M. Barrandei* are (according to Prof. Lapworth) blunt, and the apertures of the proximal thecæ hardly project at all from the ventral margin; whereas in *M. crinitus* the apertures are prolonged into a pointed claw or hook, and those of the proximal thecæ project almost as much from the ventral margin as do those of the adult thecæ. It is possible that *M. Barrandei* of Jækel may be referable to this species, but the description and figures are too meagre to afford sufficient evidence.

Locality.—Lower Winnington, on the north side of the Long Mountain.

Horizon.—Zone of *M. Nilssoni.*

Associates.—*M. varians, M. Nilssoni,* and *Retiolites* sp.

(f) Group 6. Type *M. Nilssoni* (Barr.).

1. Thecæ in contact or with slight overlap, apertures simple.
2. Polypary narrow and curved.

Monograptus Nilssoni (Barr.). (Pl. XXV, figs. 28 A & 28 B.)

1850. *Graptolithus Nilssoni*, Barrande, 'Grapt. de Bohême' p. 51 & pl. ii, fig. 16.

Polypary several inches in length, bent into a double curve proximally, almost straight distally. The width increases gradually from ·21 mm. (·008 inch) at the proximal extremity to a maximum width of 1 mm. (·04 inch) in the adult portions.

Proximal Extremity.—Sicula small but distinct, length = about 1·27 mm. (·05 inch); width at the aperture one-fifth to one-sixth of the length. Aperture concave, ventral edge produced into a long slender spine. The sicula gives origin to the first theca towards its apex, so that the apertures of the sicula and first theca are about 2 mm. (·08 inch) distant.

Fig. 24.—M. Nilssoni (*Barr.*) × *5*.

a = Proximal extremity, with sicula; from Montgomery Road.
b = Enlargement of part of fig. 28 A in Pl. XXV.
c = Enlargement of the distal thecæ of fig. 28 B in Pl. XXV.

Thecæ linear, twenty to twenty-two in the inch (eight to nine in 1 cm.), arranged on the concave side of the polypary, except at the extreme proximal end, where for a short distance they are on the convex side. Thecæ in contact only, and inclined at an angle of 10° to 25°. Outer wall slightly curved, concavo-convex; aperture concave, at right angles to the direction of the thecæ; length of thecæ = 4 to 5 times the width.

The double curvature of the polypary in its proximal portion is very characteristic, and, where this part is preserved, renders the species easily recognizable. Unfortunately, however, the adult forms generally occur in fragments, many of which, 5 to 7·6 cm. (2 to 3 inches) long, are quite straight, and show that the complete polypary must have been of considerable length. It has been generally regarded as characteristic of this species that the apertures of the thecæ are at right angles to the line of the virgula; such, however, I do not hold to be the case, that appearance being due partly to the very low inclination of the thecæ to the axis of the polypary, and partly to the special method of preservation. The sicula and its relation to the first theca as given above have not hitherto been described, and are characteristic of the species.

I have examined Barrande's type-specimen, and have had the

opportunity of collecting many specimens from his type-locality of Borek, and I feel no doubt that our English species agrees in every particular with the Bohemian form. It is probably also identical with the Swedish form *Monograptus Nilssoni*, described by Tullberg,[1] though in his plate the whole polypary is not figured and the thecæ are shown as rather more closely set.

The nearest relation of *M. Nilssoni* is undoubtedly the so-called *Cyrtograptus Carruthersi* of the Upper Wenlock Beds, fragments of which are indistinguishable from similar fragments of *M. Nilssoni* when both are similarly preserved.

Range.—In Britain there is little doubt that *M. Nilssoni*, in its characteristic form, is confined to the Lower Ludlow Beds, outside of which I have myself never found it. I have collected it at Borek (Bohemia) in association with the Ludlow forms *M. colonus* var. and *Retiolites spinosus.*

Foreign Localities.—Bohemia (Borek, Vyskočilka, etc.); Scandinavia (Hjontaröd, Knutsdorp, Tibaröd, etc.); Saxony; Thuringia; Harz Mountains; Graptolithengestein (Ronneburg and Gräfenwerth); France (Languedoc, Normandy, Britanny, etc.).

British Localities.—Ludlow district (Elton Lane, Elton–Ludlow Road, Adferton, etc.); Builth (R. Irfon, etc.); Long Mountain (Old Dingle Mill, etc.); Montgomery Road; Lake District.

Associates.—*M. bohemicus*, *M. colonus* and its variety *compactus*, *M. varians* and its variety *pumilus*, *M. Rœmeri*, *M. dubius*, *M. uncinatus* var. *orbatus* and var. *micropoma*, etc.

Monograptus bohemicus (Barr.). (Pl. XXV, figs. 27 A & 27 B and text-fig. 25, p. 484.)

1850. *Graptolithus bohemicus*, Barrande, 'Graptolites de Bohême' p. 40 & pl. i, figs. 15–18.

Polypary gracefully bent, the proximal part being curved almost into a semicircle, while the distal end has a broader sweep, becoming eventually almost straight. Fragments 7·5 to 10 cm. (3 to 4 inches) long are found, so that the polypary must have reached a considerable length. The width increases gradually from ·36 mm. (·014 inch) at the proximal end to 2 mm. (·08 inch) distally. The virgula projects slightly at the distal end.

Proximal Extremity.—Sicula very characteristic, about ·85 to 1 mm. (·03 to ·04 inch) long, and ·32 mm. (·012 inch) wide at the aperture, so that it is only $2\frac{1}{2}$ to 3 times as long as wide. The apex does not quite extend to the level of the aperture of the first theca, which is inclined to the sicula at an angle of about 45°. Aperture furnished with a long and stout spine.

Thecæ.—Twenty-seven to twenty-three in the inch (eleven to nine in 1 cm.), occurring on the concave side of the polypary. Thecæ in contact merely, or with a slight overlap in the more distal thecæ, inclined to the axis at an angle of about 30° to 35°. They

[1] 'Skånes Graptoliter' pt. ii (1883) Sver. Geol. Undersökn. ser. C, no. 55, p. 17 & pl. i, figs. 31–32.

are short broad tubes, only about 2 to 3 times as long as wide; the outer wall is constricted where it is in contact with the theca below, but convex above, the aperture being concave and fairly wide, and provided with a small denticle.

Fig. 25.—M. bohemicus (*Barr.*) ×5.

a=Distal thecæ; from the River Irfon, Builth.
b=Proximal extremity, with sicula; from the Elton-Ludlow Road.
c=Distal extremity; from the Elton-Ludlow Road.

There are few species so readily recognizable as this one, and it has been correctly identified by most observers. Nicholson, however, confused it with a Llandovery species which has a strong convex curvature. Prof. Frech regards *Monograptus bohemicus* as a 'doubtful species' resembling his *Linograptus Nilssoni*. Barrande reckons only twenty thecæ to the inch in his description of *M. bohemicus* (though in his figures there are twenty-three), but in all the English specimens there are as many as twenty-seven at the proximal end, and in none are there so few as twenty, even in the adult parts. The sicula and its position with regard to the first theca were first figured by Tullberg, and are very characteristic of this species, being quite different from that of *M. Nilssoni*. The general form of the polypary varies somewhat at different localities: thus, in the Ludlow district the specimens are small and strongly curved; while at Builth they often reach a considerable length, and the distal part is almost straight; in the Dee Valley they are long, but curved throughout. I do not consider, however, that these variations in shape are worthy of varietal names.

Foreign Localities.—Scania (Röstånga, Ask, Billinge, Pugerup, Röfvarekulan, Harlösa, Heinge, Djurröd, Tosterup, Tolonga); Bohemia (Butowitz, Vyskočilka, Kozel, Kosoř, Kuchelbad, etc.); Thuringia; Harz Mountains; Graptolithengestein (Kunzendorf, Rexdorf, Gräfenwerth); Polnisches Mittelgebirge; France (Languedoc, Ardennes, Normandy, and Britanny).

British Localities.—Ludlow district (Elton Lane, Elton-Evenhay Lane, Elton-Ludlow Road, etc.); Long Mountain (north side); Builth district (Aberedw Hill, River Irfon, etc.); Lake District (Helm Knot).

Horizon.—*M. bohemicus* ranges throughout the greater part of the Lower Ludlow, but is most characteristic of the zone of *M. Nilssoni*. In Sweden, Bohemia, etc., it occurs in the *Cardiola*-beds.

Associates.—*M. Nilssoni*, *M. scanicus*, *M. chimæra*, *M. colonus*, *M. varians*, *M. tumescens*, *M. uncinatus* var. *micropoma*, and *Retiolites spinosus*.

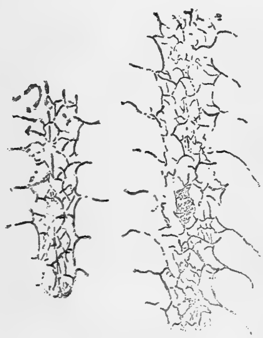
2. Genus *Retiolites*.

Retiolites spinosus, sp. nov. (Pl. XXV, figs. 29 A & 29 B.)

Polypary diprionidian, straight, from 12·7 to 19 mm. (·5 to ·75 inch) long. Virgula straight, produced beyond the distal end. Width at proximal extremity = about ·89 mm. (·035 inch), increasing gradually and uniformly to a maximum diameter of 1·78 mm. (·07 inch), exclusive of thecal spines.

Proximal Extremity.—I have not been able to determine with certainty the details of the proximal extremity. The aperture of the first theca is ·6 mm. (·024 inch) above the base, so that the initial canal, if existent, must be very short. There appears, however, to be a true sicula with a continuous periderm ·5 mm. (·03 inch) long, extending halfway between the first and second thecæ, and continuous with the virgula (text-fig. 26 *a*).

Fig. 26.—Retiolites spinosus, *sp. nov., from Vicarage Road, Builth (×5).*



a *b*

a=Proximal extremity.
b=Enlargement of fig. 29 A in Pl. XXV.

Thecæ.—Twenty-eight to twenty-six in 1 inch (eleven to ten in 1 cm.). The apertures appear to be at right angles to the axis of the polypary, and are each provided with one or two long spines, 1·01 mm. (·04 inch) and more in length, which are generally straight and directed at right angles to the polypary. In the British specimens one spine alone is usually visible, arising from the aperture of each theca; but in Bohemian specimens collected from Borek the polypary has not been compressed quite symmetrically, and there are two spines visible. Consequently it is probable that there are two in the English forms. It is difficult, in the compressed state of the specimens, to make out the details of the network. Main threads would seem to arise from the virgula and outline the apertures of the thecæ. The outer walls between the apertures are angular and concave, giving to the outer edge of the polypary a zigzag appearance. Straight threads at right angles to the polypary connect these angles with the virgula. The details of the network, however, will be best seen from the figures.

Affinities.—*Retiolites spinosus* may be readily distinguished from all other species of the genus by (*a*) the general shape of the polypary, and (*b*) the long thecal spines. It is one of the most characteristic forms that occur in the zone of *Monograptus Nilssoni*, especially in the Builth district, where it is found covering large

surfaces of rock with a delicate network of threads. In Bohemia I have obtained it at a similar, and also at a slightly lower horizon. At one locality it was associated with *Monograptus Nilssoni* and a variety of *M. colonus*; at another it occurred together with *Cyrtograptus Lundgreni*, *Monograptus testis*, *Retiolites nassa*, etc.

Foreign Localities.—Bohemia (Borek).

British Localities.—Builth (River Irfon, etc.); Long Mountain (Trefnant–Middletown Brook); Montgomery Road.

Horizon.—Zone of *M. Nilssoni.*

Associates.—*M. Nilssoni*, *M. bohemicus*, *M. colonus*, *M. varians*, and *M. dubius*.

RETIOLITES NASSA, Holm (*Gothograptus*, Frech). (Pl. XXV, fig. 30.)

1890. *Retiolites nassa*, Holm, 'Gotlands Graptoliter' Bihang till K. Svenska Vet.-Akad. Handling. vol. xvi, pt. iv, no. 7, p. 25 & pl. ii, figs. 12–14.

This characteristic little species has hitherto been obtained from but one locality in Britain, and there only in a fragmentary condition. The species has been so fully diagnosed by Holm and Wiman that a complete description here is unnecessary. It can be readily recognized by the following characters:—

(1) Polypary seldom exceeding 6 or 7 mm. (·025 to ·03 inch) in length;
(2) Margin of polypary entire;
(3) Long initial canal present, terminating proximally in a spine; and
(4) Thecal apertures resembling those of *Climacograptus.*

Fig. 27.— Retiolites nassa, *Holm* (× 5).

[Enlargement of fig. 30 in Pl. XXV.]

Foreign Localities. — Gotland; Bohemia (Borek).

British Locality.—South side of the Long Mountain, near Worthen.

Horizon.—*M.-vulgaris* zone in Britain. Abroad it occurs in the highest zone of the Wenlock, that of *M. testis*, and at the base of the Lower Ludlow Beds in association with *M. Nilssoni.*

Associate.—*M. vulgaris.*

In conclusion, I should like to express my sincere thanks to Prof. Watts, M.A., Sec.G.S., for generously placing at my disposal his collection of graptolites from the Long Mountain and his field-maps of the country; to Mr. Marr, F.R.S., for his kind permission to examine his graptolites from the Lake District; to my colleague and friend, Miss G. L. Elles, in whose company much of my work in the field was done, and with whom many points have been freely

face p. 486.

LE IV.—DISTI

YPARY.	
General shape.	racter pertures.
ight distally, in- rved proximally.	enticle.
ble curvature.	r with denticle [. *dubius.*
ight distally, in- rved proximally.	„
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ed throughout.	
n *M. dubius.*	nt denticle.
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M. dubius.	
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M. dubius.	es.
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M. dubius.	es proximally, listally.
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gly curved.	v.
ous.	
g double curve.	ncave aperture.
ircular curve at proximal end.	oncave, with enticle.

Table IV.—Distinctive Characters of the Lower Ludlow Graptolites.

Species.	Polypary. Length in cm.	Maximum width in mm.	Minimum width in mm.	General shape.	Distal prolongation of virgula.	Proximal Extremity. Length of sicula.	Width of sicula.	Angle of inclination of first theca to sicula.	Apparent point of origin of first theca and sicula.	Level of apex of sicula.	Thecæ. Number to the inch.	Angle of inclination.	Length of adult thecæ.	Proportion of length to width.	Amount of overlap in adult thecæ.	Number of types of thecæ.	Character of apertures.
Monograptus dubius (Suess)	3-10	2	·76	Straight distally, incurved proximally.	None.	1·77-2	·31	20°	At aperture.	2nd thecal aperture.	25 20	30°	2·54	$2\frac12$ 3	$\frac14-\frac13$	1	Pointed denticle.
M. vulgaris, sp. nov.	5-10	2·54	·76	Double curvature.	Slight.	2	·5	30	Above aperture.	2nd thecal aperture.	28 24	35-40	2·75	4	$\frac12$	1	Simple, or with denticle as in *M. dubius*.
—— var. *α* nov.	5	2·54	·76	Straight distally, incurved proximally.	?	Same as in *M. vulgaris*.					26-22	„	2·40	3	$\frac13$	1	„
—— var. *β* nov.	6	2	·76	Straight distally, strong proximal curvature.	...	2	·5	30	Slightly above aperture.	2nd thecal aperture.	30-26	„	2·27	4	$\frac13-\frac12$	1	Simple.
M. tumescens, sp. nov.	2·5-3·8	2	·76	As in *M. dubius*.	None.	1·9	·38	20	At aperture.	Second theca.	28-24	30	2·54	4	$\frac13$ $\frac12$	1	Simple, or with blunt denticle.
—— var. *minor* nov.	1·25	1·6	·76	Curved throughout.	None.	Same as in *M. tumescens*.					28-30	Same as in *M. tumescens*.					
M. gotlandicus, Perner	3·2	2·03	·76	As in *M. dubius*.	?	2·03	·36	25	At aperture.	?	23-20	25-35	3—	$4\frac12$	$\frac12-\frac13+$	1	Long blunt denticle.
M. comis, sp. nov.	2·5	1·27	·51	„ „	Slight.	1·77	·38	25	Near aperture.	?	29-28	25-30	1·77	3-4	Very slight.	1	Pointed denticle.
M. ultimus, Perner	1·27-2·0	1·6	·63	„ „	None.	1·9	·38	30-35	Distinctly above aperture.	Second theca.	30-28	30-40	1·6	3-4	In contact only or slight overlap.	1	Simple.
M. colonus (Barr.)	3·8-5·8	2·3	·84	„ „	Slight.	1·9	·32	45	Slightly above aperture.	„	32-26	40	2·6	4+	$\frac13-\frac12$	2	Recurved proximally, simple distally.
—— var. *ludensis* (Murch.)	2·5-5·0	2·5	1	„ „	6·3 mm. long.	2	·36	40	„	„	34-26	30-35	2·9	5-6	$\frac12+$	2?	Distal apertures simple.
—— var. *compactus* nov.	1·9-2·5	2	·76	Curved throughout.	Stout and well marked.	1·27	·25	40	„	„	42-37	40-50	2·4	$4\frac12$	$\frac12-\frac23$	2	As in *M. colonus*.
M. Rœmeri (Barr.)	3-7	3·6-4·2	·89	Double curvature.	2 cm. or more.	1·8	·32	40-45	„	„	34-28	40-45	3·8	$5-5\frac12$	$\frac23$	2	„
M. varians, sp. nov.	2·5	1·77	·76	As in *M. dubius*.	12·7 mm.	2	·36	40	„	Above second theca.	32-26	30-35	2·2	$3\frac12-4$	$\frac14$	2	„
—— var. *α* nov.	2·5	2·1	·76	„ „	Long.	2	·36	40	„	„	35-28	40	2	$3\frac12$	$\frac14+$	2	„
—— var. *β* nov.	3·8	1·7	·76	„ „	Slight.	2	·36	40	„	Between second & third thecæ.	36-30	35-40	2	$3\frac12-4$	$\frac14$	2	„
—— var. *pumilus* nov.	1·27	1·6	·76	Nearly straight throughout.	Very slight.	1·9	·32	35-40	·25 mm. above aperture.	Near third theca.	42-36	35-40	1·6	$3\frac12$	$\frac13-\frac12$	2	„
M. chimæra (Barr.)	2·5-3·8	1·9	·89	As in *M. dubius*.	Slight.	1·7	·34	35-40	Above aperture.	Between second & third thecæ.	32-28	40-50	2+	2-4	$\frac12$	1	Stout spines.
—— var. *Salweyi* (Hopk.)	1·27	1·6	·72	Straight throughout.	Very long.	1·9	·32	35-40	Above aperture.	Above second theca.	34-30	35-40	2	4	$\frac13-\frac12$	1	Long slender spines.
—— var. *α*	2·5-3·8	2·5	·72	As in *M. dubius*.	...	Same as in *M. chimæra*.					36-28	40-45	2·5	$3\frac12$	$\frac13-\frac23$	2	Stout spines proximally, simple distally.
M. leintwardinensis, Hopk.	1·27	1·6	·85-1	„ „	Slight.	2·1	·38	35-40	·4 mm. above aperture.	Between 2nd & 3rd thecæ.	38-36	35-45	1·7	$3\frac12$	$\frac12$—	1	Long curved spines.
—— var. *incipiens* nov.	1·27	1·9-2·1	·72	„ „	Very long.	1·9	·42	35-40	·3 mm. above aperture.	Above second theca.	40-37	40-50	2·54	4	$\frac12-\frac23$	2	Long spines in proximal thecæ.
M. uncinatus, var. *orbatus* nov.	2·5-5·0	1·9	·76	Double curvature.	Slight.	1·6	·32	30	Slightly above aperture.	Second theca.	30-24	30-35	1·27	2—	In contact or with slight overlap.	1	Spinose claw.
—— var. *micropoma* (Jækel)	2·54	1·27	·5	Nearly straight.	Slight.	1·27	·25	25-30	Near aperture.	Between 1st & 2nd thecæ.	26-22	25 30	1·27	2 3	„	1	Small spinose claw.
M. scanicus, Tullb.	10-15	1	·25	Strongly curved.	None.	1·5	·23	10	·5 mm. above aperture.	First theca.	20-23	10-20	2	7-5	In contact.	1	Small claw.
M. crinitus, sp. nov.	7·5+	·38	·19	Flexuous.	None.	1·4	·21	10	·6 mm. above aperture.	Near first theca.	14-18	5-10	1·6	8-6	„	1	„
M. Nilssoni (Barr.)	8-12?	1	·21	Strong double curve.	None.	1·27	·23	10	·76 mm. above aperture.	Considerably below first theca.	20 22	10-25	2	5-4	„	1	Simple concave aperture.
M. bohemicus (Barr.)	10-15?	2	·36	Semicircular curve at the proximal end.	Slight.	·85-1	·32	45	·25 mm. above aperture.	„	27-23	30-35	1·8	2-3	In contact or with slight overlap.	1	Widely concave, with slight denticle.

discussed; and above all, my gratitude to Prof. Lapworth, F.R.S., who has granted me every facility for my work, and has helped me throughout with advice and sympathy.

[NOTE.—All the figures of graptolites were drawn by me with the Parkes-Lapworth microscope in the Research Section of the Geological Department, Mason University College, Birmingham. Unless otherwise indicated, the specimens figured are in my own collection.]

(C) Synonymy.

MONOGRAPTUS DUBIUS (Suess).

1850. *Graptolithus colonus*, Barrande, 'Graptolites de Bohême' p. 43 & pl. ii, fig. 5.
1851. *Gr. dubius*, Suess, 'Ueber Böhmische Graptolithen' Haidinger's Abhandl. vol. iv, pt. iv, p. 115 & pl. ix, figs. 5 *a*–5 *b*.
1876. *Monograptus dubius*, Lapworth, Geol. Mag. 1876, p. 33 & pl. xx, fig. 10.
1878. *M. dubius*, Kayser, 'Die Fauna der ältesten Devon-Ablagerungen des Harzes' Abhandl. geol. Specialkarte von Preussen, vol. ii, pt. iv, p. 215 & pl. xxxi, figs. 19–22.
1880. *M. serra*, Hopkinson MS., Lapworth, 'New British Graptolites' Ann. & Mag. Nat. Hist. ser. 5, vol. v, pl. iv, figs. 6 *c* & 6 *d*.
1883. *M. dubius*, Tullberg, 'Skånes Graptoliter' pt. ii, Sver. Geol. Undersökn. ser. C, no. 55, p. 29 & pl. i, figs. 28–29; pl. ii, figs. 20–21.
1890. *M. dubius*, Holm, 'Gotlands Graptoliter' Bihang till K. Svenska Vet.-Akad. Handling. vol. xvi, pt. iv, no. 7, pp. 16, 17 & pl. i, figs. 18–26.
1893. *M. dubius*, Wiman, 'Ueber *Monograptus*' Bull. Geol. Inst. Upsala, vol. i, no. 2, p. 2 & pl. vii.

MONOGRAPTUS TUMESCENS, sp. nov.

1868. *Graptolites colonus*, Nicholson, Quart. Journ. Geol. Soc. vol. xxiv, pp. 540–41 & pl. xx, figs. 9–11.
1889. *Pristiograptus frequens?* Jækel, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xli, p. 669 & pl. xxviii, figs. 1–2.

MONOGRAPTUS GOTLANDICUS, Perner.

1890. *Monograptus* sp., Holm, 'Gotlands Graptoliter' p. 18 & pl. i, figs. 27–30.
1899. *M. gothlandicus*, Perner, 'Études sur les Graptolites de Bohême' pt. iii, sect. *b*, p. 12 & pl. xiv, fig. 22.

MONOGRAPTUS COLONUS (Barrande).

1850. *Graptolithus colonus*, Barrande, 'Graptolites de Bohême' p. 42 & pl. ii, figs. 2–3; non 1, 4, 5.
1851. Non *Gr. colonus*, Suess, 'Ueber Böhmische Graptolithen' pp. 116–117, & pl. viii, fig. 8.
1852. ? *Gr. colonus*, Geinitz, 'Die Graptolithen... der Grauwackenformation in Sachsen' p. 38 & pl. ii, figs. 33–36.
1868. Non *Gr. colonus*, Nicholson, Quart. Journ. Geol. Soc. vol. xxiv, p. 540–41 & pl. xx, figs. 9–11.
1869. ? *Monograptus colonus*, Heidenhain, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxi, p. 146.
1876. Non *M. colonus*, Lapworth, Geol. Mag. p. 505 & pl. xx, figs. 9 *a*–*c*.
1876. ? Non *M. colonus*, Haupt, 'Die Fauna des Graptolithengesteines' Neues Lausitz. Mag. vol. liv, pp. 19–20.
1878. ? *M. colonus*, Kayser, 'Die Fauna der ältesten Devon-Ablagerungen des Harzes' pl. xxxi, figs. 17 & 18.
1880. Non *M. colonus*, Lapworth, Ann. & Mag. Nat. Hist. ser. 5, vol. v, p. 153 & pl. iv, figs. 3 *a*–3 *c*.
1880. *M. Rœmeri*, Lapworth, *ibid.* p. 151 & pl. iv, figs. 5 *a*–5 *c*.
1883. *M. colonus*, Tullberg, 'Skånes Graptoliter' pl. i, figs. 22 & 23.

1884. Non *Monograptus colonus*, J. D. La Touche, 'Handbook to the Geology of Shropshire' p. 78 & pl. xviii, fig. 577.

1889. Non *Pristiograptus colonus*, Jækel, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xli, p. 674 & pl. xxviii, fig. 7.

1890. *Monograptus colonus*, Geinitz, 'Die Graptolithen d. k. Min. Mus. in Dresden' Mitth. d. k. Min. Geol.-Prähist. Mus. Dresden, pt. ix, pp. 15, 16 & pl. A, fig. 14.

1892. *M. colonus*, Barrois, 'Distribution des Graptolites en France' Ann. Soc. Géol. Nord, vol. xx, p. 100.

1897. *Pristiograptus colonus*, Frech, 'Lethæa Geognostica' vol. i, pt. iii, pp. 655–656, fig. 209.

1899. *Monograptus colonus*, Perner, 'Études sur les Graptolites de Bohême' pt. iii, sect. *b*, p. 9, pl. xiv, figs. 3, 12, 17 & text-fig. 12.

Var. LUDENSIS (Murchison).

1839. *Graptolithus ludensis*, Murchison, 'The Silurian System' pl. xxvi, fig. 2.

1855. Non *Monograptus ludensis*, M'Coy, 'Brit. Palæoz. Foss.' p. 4.

1879. ? *Graptolithus ludensis*, Quenstedt, 'Petrefactenkunde Deutschl.' vol. vi, pp. 192–93 & pl. cl, fig. 29.

MONOGRAPTUS RŒMERI (Barrande).

1850. *Graptolithus Rœmeri*, Barrande, 'Graptolites de Bohême' p. 41 & pl. ii, figs. 9–11.

1869. *Monograptus Rœmeri*, Heidenhain, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxi, p. 150 & pl. i, fig. 5.

1879. *Graptolithus colonus*, Quenstedt, 'Petrefactenkunde Deutschl.' vol. vi, pl. cl, fig. 40.

1880. Non *Monograptus Rœmeri*, Lapworth, Ann. & Mag. Nat. Hist. ser. 5, vol. v, pl. iv, figs. 5 *a*–5 *c*.

1883. ? *M. colonus*, Tullberg, 'Skånes Graptoliter,' pl. i, fig. 21.

1884. *M. Rœmeri*, J. D. La Touche, 'Handbook to the Geology of Shropshire' p. 78 & pl. xviii, fig. 578.

1897. *Pristiograptus Rœmeri*, Frech, 'Lethæa Geognostica' pt. iii, p. 656, fig. 210.

1899. *Monograptus Rœmeri*, Perner, 'Études sur les Graptolites de Bohême' pt. iii, sect. *b*, p. 8, pl. xiv, figs. 1, 7, 10, 18, 24 & text-fig. 11.

MONOGRAPTUS CHIMÆRA (Barrande).

1850. *Graptolithus chimæra*, Barrande, 'Graptolites de Bohême' p. 52 & pl. iv, figs. 34–35.

1884. Non *Monograptus chimæra*, J. D. La Touche, 'Handbook to the Geology of Shropshire' p. 77 & pl. xviii, fig. 571.

1889. *Pristiograptus colonus*, Jækel (?) Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xli, p. 674 & pl. xxviii, fig. 8.

1899. *Monograptus chimæra*, Perner, 'Études sur les Graptolites de Bohême' pt. iii, sect. *b*, p. 14 & pl. xvii, figs. 15 *a*–15 *b*.

Var. SALWEYI (Hopkinson MS.).

1880. *Monograptus Salweyi*, Lapworth, Ann. & Mag. Nat. Hist. ser. 5, vol. v, p. 150 & pl. iv, figs. 2 *a*–2 *b*.

1884. *M. chimæra*, J. D. La Touche, 'Handbook to the Geology of Shropshire' p. 77 & pl. xviii, fig. 571.

MONOGRAPTUS LEINTWARDINENSIS, Hopkinson MS.

1880. *Monograptus leintwardinensis*, Lapworth, Ann. & Mag. Nat. Hist. ser. 5, vol. v, p. 149 & pl. iv, fig. 1.

1884. *M. leintwardinensis*, J. D. La Touche, 'Handbook to the Geology of Shropshire' p. 77 & pl. xviii, fig. 574.

1897. *Pristiograptus uncinatus*, Frech, 'Lethæa Geognostica' pt. iii, p. 658, fig. 213.

MONOGRAPTUS UNCINATUS var. MICROPOMA (Jækel).

1869. *Monograptus* sp., Heidenhain, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxi, p. 151 & pl. i, fig. 6.

1889. *Pomatograptus micropoma*, Jækel, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xli, p. 682 & pl. xxix, figs. 4–6.

1897. Non *Monoclimacis spinulosa* (Tullb.) Frech, 'Lethæa Geognostica' vol. i, pt. iii, p. 623.

MONOGRAPTUS SCANICUS, Tullberg.

1869. *Monograptus distans* (Portl.) Heidenhain, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxi, p. 147 & pl. i, fig. 1.
1876. *M. distans?* (Portl.) Haupt, 'Die Fauna des Graptolithengesteines' p. 20 & pl. iv, fig. 1.
1883. *M. scanicus*, Tullberg, 'Skånes Graptoliter' p. 26 & pl. ii, figs. 38–44.
1884. *M. clavicula*, Hopk. MS.? see J. D. La Touche, 'Handbook to the Geology of Shropshire' p. 78 & pl. xviii, fig. 575.
1889. *Pomatograptus Becki*, Jækel, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xli, p. 683 & pl. xxix, figs. 7–9.
1897. *M. cygneus*, Frech, 'Lethæa Geognostica' vol. i, pt. iii, p. 644, fig. 199.

MONOGRAPTUS NILSSONI (Barrande).

1850. *Graptolithus Nilssoni*, Barrande, 'Grapt. de Bohême' p. 51 & pl. ii, fig. 16.
1851. *Gr. Nilssoni*, Suess, 'Ueber Böhmische Graptolithen' p. 119.
1851. Non *Gr. Nilssoni*, Harkness, Quart. Journ. Geol. Soc. vol. vii, p. 61 & pl. i, figs. 7 *a*–7 *d*.
1852. *Monograptus Nilssoni*, Geinitz, 'Die Graptolithen ... der Grauwacken-formation in Sachsen' p. 35 & pl. ii, figs. 17–20, 24, 25, 28–32 (?).
1867. Non *Graptolites Nilssoni*, Baily, 'Characteristic Brit. Foss.' pl. ix, figs. 2 *a*–*b*.
1868. Non *Gr. Nilssoni*, Nicholson, Quart. Journ. Geol. Soc. vol. xxiv, pl. xx, fig. 19.
1869. *Monograptus Nilssoni*, Heidenhain, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxi, p. 147 & pl. i, fig. 2.
1876. *M. Nilssoni*, Lapworth, Geol. Mag. p. 315 & pl. x, figs. 7 *a*–*c*.
1876. *M. Nilssoni*, Haupt (?) 'Die Fauna des Graptolithengesteines' p. 21 & pl. iv, fig. 3 (?).
1878. *M. Nilssoni*, Kayser, 'Die ältesten Devon-Ablagerungen des Harzes' p. 217 & pl. xxxi, fig. 12 (fig. 25 ?).
1883. *M. Nilssoni*, Tullberg, 'Skånes Graptoliter' pl. i, figs. 31, 32.
1884. *M. Nilssoni*, J. D. La Touche, 'Handbook to the Geology of Shropshire' p. 78 & pl. xviii, fig. 576.
? 1885. *M. scanicus*, Rœmer, *non* Tullberg, 'Lethæa Erratica,' pl. ix, figs. 13 *a*, *b*.[1]
1889. *Pristiograptus Nilssoni*, Jækel, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xli, p. 673 & pl. xxviii, fig. 7.
1890. *Monograptus Nilssoni*, Geinitz, 'Die Graptolithen d. k. Min. Mus. in Dresden' p. 13 & pl. A, fig. 7 (in part) *non* fig. 8.
1892. *M. Nilssoni*, Barrois, 'Distribution des Graptolites en France' pp. 101, 121.
1897. *Linograptus Nilssoni*, Frech, 'Lethæa Geognostica' vol. i, pt. iii, p. 662, fig. 218.
1899. *Monograptus Nilssoni*, Perner, 'Études sur les Graptolites de Bohême' pt. iii, sect. *b*, p. 7 & pl. xvii, figs. 1, 2, 7.

MONOGRAPTUS BOHEMICUS (Barrande).

1850. *Graptolithus bohemicus*, Barrande, 'Graptolites de Bohême' p. 40 & pl. i, figs. 15–18.
1851. *Gr. bohemicus*, Suess, 'Ueber Böhmische Graptolithen' pp. 110–111 & pl. viii, figs. 6 *a*–*e*.
1851. ? *Gr. Barrandei*, Scharenberg, 'Ueber Graptolithen, etc.' Inaug. Dissert. (Breslau) p. 15 & pl. i, figs. 5–5 *a*.
1852. *Monograptus bohemicus*, Geinitz, 'Die Graptolithen ... der Grauwacken-formation in Sachsen' p. 36 & pl. ii, fig. 41.
1868. Non *M. bohemicus*, Nicholson, Quart. Journ. Geol. Soc. vol. xxiv, p. 539 & pl. xx, figs. 22–24.
1869. *Graptolithus bohemicus*, Heidenhain, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxi, p. 149 & pl. i, figs. 4 *a*–*c*.
1876. *Monograptus bohemicus*, Haupt, 'Die Fauna des Graptolithengesteines' p. 19.
1881. *Graptolithus scalaris*, Quenstedt, 'Petrefactenkunde Deutschl.' vol. vi, pl. cl, fig. 44.
1883. *M. bohemicus*, Tullberg, 'Skånes Graptoliter,' pl. iii, figs. 3–5.
1884. *M. bohemicus*, J. D. La Touche, 'Handbook to the Geology of Shropshire' p. 77 & pl. xviii, fig. 573.
1889. *Pristiograptus bohemicus*, Jækel, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xli, p. 672 & pl. xxviii, figs. 3–6.
1890. *Monograptus bohemicus*, Geinitz, 'Die Graptolithen d. k. Min. Mus. in Dresden' p. 14 & pl. A, fig. 10.

1892. *Monograptus bohemicus,* Barrois, 'Distribution des Graptolites en France' p. 99.

1897. *Pristiograptus bohemicus,* Frech, 'Lethæa Geognostica,' vol. i, pt. iii, p. 664.

RETIOLITES NASSA, Holm.

1890. *Retiolites nassa,* Holm, 'Gotlands Graptoliter' p. 25 & pl. ii, figs. 12–14.

1895. *R. nassa,* Wiman, 'Ueber die Graptolithen' Bull. Geol. Inst. Upsala, vol. ii, no. 2, pls. ii & xi.

1899. *R. nassa,* Perner, 'Études sur les Graptolites de Bohême' pt. iii, sect. *b*, p. 23, text-figs. 32 *a*–32 *b* & pl. xvii, figs. 20–21.

EXPLANATION OF PLATES XXV & XXVI.

PLATE XXV.

[All the figures are of the natural size.]

Fig. 1. *Monograptus dubius* (Suess). 1 A. Elton Lane (*M. serra* of Mr. Hopkinson's collection); 1 B. Stormer Hall.

Figs. 2–4. *M. vulgaris,* sp. nov. Trefnant–Middletown Brook, Long Mountain (Loc. 3 in Pl. XXVI).
- 3. Var. *a* nov. Trefnant–Middletown Brook, Long Mountain (Loc. 5 in Pl. XXVI).
- 4. Var. *β* nov. Lane Farm, Long Mountain.

5 & 6. *M. tumescens,* sp. nov. 5 A. Llettygynfach, Long Mountain. Coll. C. Lapworth. 5 B. Elton–Ludlow Road, Gorsty Farm.
- 6. Var. *minor* (M'Coy). 6 A. Elton–Ludlow Road. 6 B. Elton Lane.

Fig. 7. *M. gotlandicus,* Perner. Old Dingle Mill, Long Mountain. Coll. W. W. Watts.

8. *M. comis,* sp. nov. 8 A. Elton–Ludlow Road. 8 B. Reverse side of 8 A.

9. *M. ultimus,* Perner. 9 A. Road between County Bridge and Ucheldre, Long Mountain (Loc. 15 in Pl. XXVI). Coll. W. W. Watts. 9 B. Kosor, Bohemia. Coll. C. Lapworth.

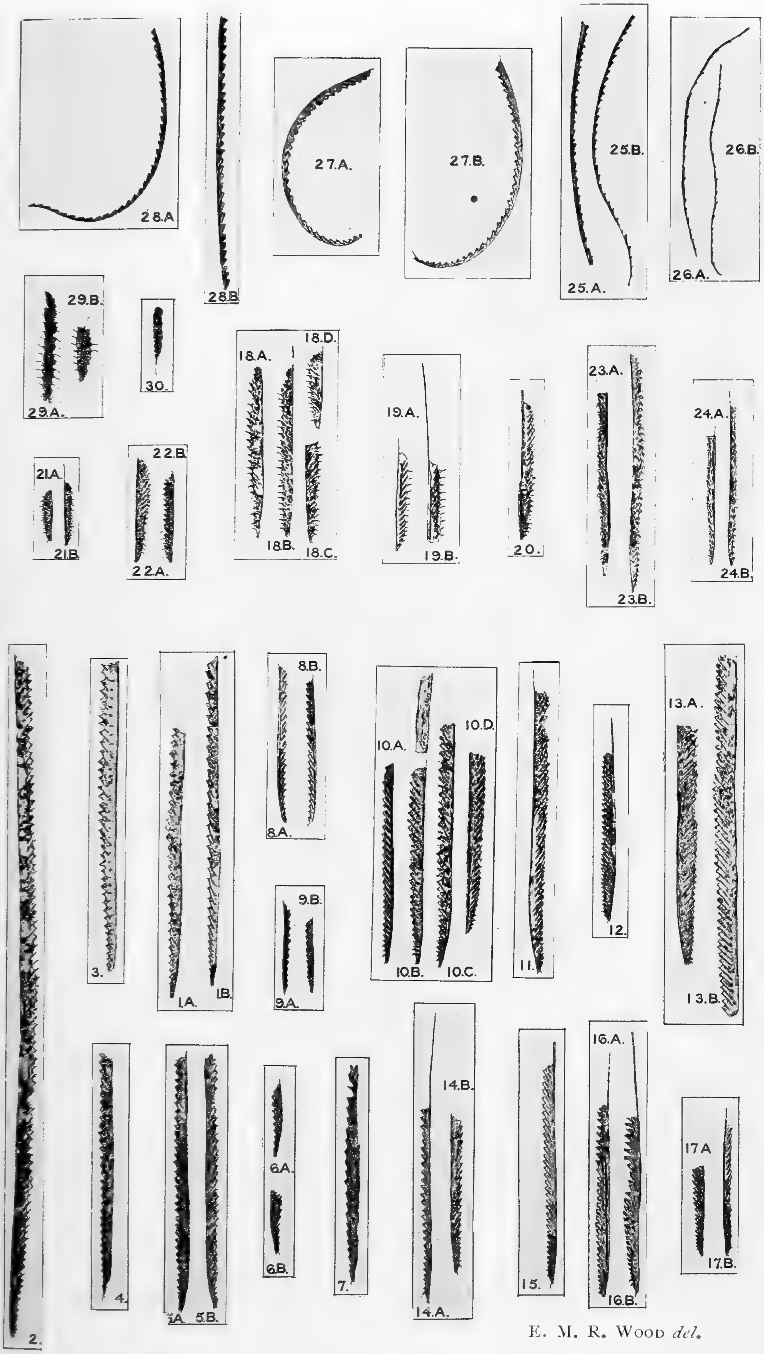
Figs. 10–12. *M. colonus* (Barrande). 10 A. Butowitz, Bohemia. Coll. C. Lapworth. 10 B. Helm Knot, Lake District. Coll. Nat. Hist. Mus. S. Kensington. 10 C. R. Irfon, Builth (Loc. C′ in fig. 5, p. 432). 10 D. Adferton. Coll. J. Hopkinson.
- 11. Var. *ludensis* (Murch.). Llanfair, Montgomeryshire. Coll. Dr. Humphreys, Llanfair.
- 12. Var. *compactus* nov. Elton–Evenhay Lane.

Fig. 13. *M. Rœmeri* (Barr.). A & B. Trefnant–Middletown Brook, Long Mountain (Loc. 6 in Pl. XXVI).

Figs. 14–16. *M. varians,* sp. nov. 14 A. Old Dingle Mill, Long Mountain. 14 B. Road above Garbett's Hall, Long Mountain.
- 15. Var. *β* nov. Elton Lane.
- 16. Var. *a* nov. 16 A. Stormer Hall. 16 B. Mary Knoll, near Ludlow. Coll. J. Hopkinson. Figured in Ann. & Mag. Nat. Hist. ser. 5, vol. v (1880) pl. iv, figs. 3 *b* & 3 *d*.
- 17. Var. *pumilus* nov. 17 A. Elton Lane (Loc. D in fig. 2, p. 426). 17 B. *Ibid.* (Loc. G in fig. 2).

18–20. *M. chimæra* (Barr.). 18 A, C, D. Elton–Ludlow Road. 18 B. Stream from Ucheldre to Trewern Bridge, Long Mountain. Coll. W. W. Watts.
- 19. Var. *Salweyi* (Hopk.). 19 A. Stormer Hall. 19 B. *Ibid.* Coll. J. Hopkinson. Figured in Ann. & Mag. Nat. Hist. ser. 5, vol. v. (1880) pl. iv, figs. 2 *a* & 2 *b*.
- 20. Var. *a* nov. Elton–Ludlow Road.

21 & 22. *M. leintwardinensis,* Hopk. 21 A, B. Church Hill Quarry, near Leintwardine. Coll. J. Hopkinson.
- 22. Var. *incipiens* nov. 22 A. Montgomery Road. 22 B. Long Mountain. Coll. W. W. Watts.



E. M. R. Wood *del.*

Lower Ludlow Graptolites.

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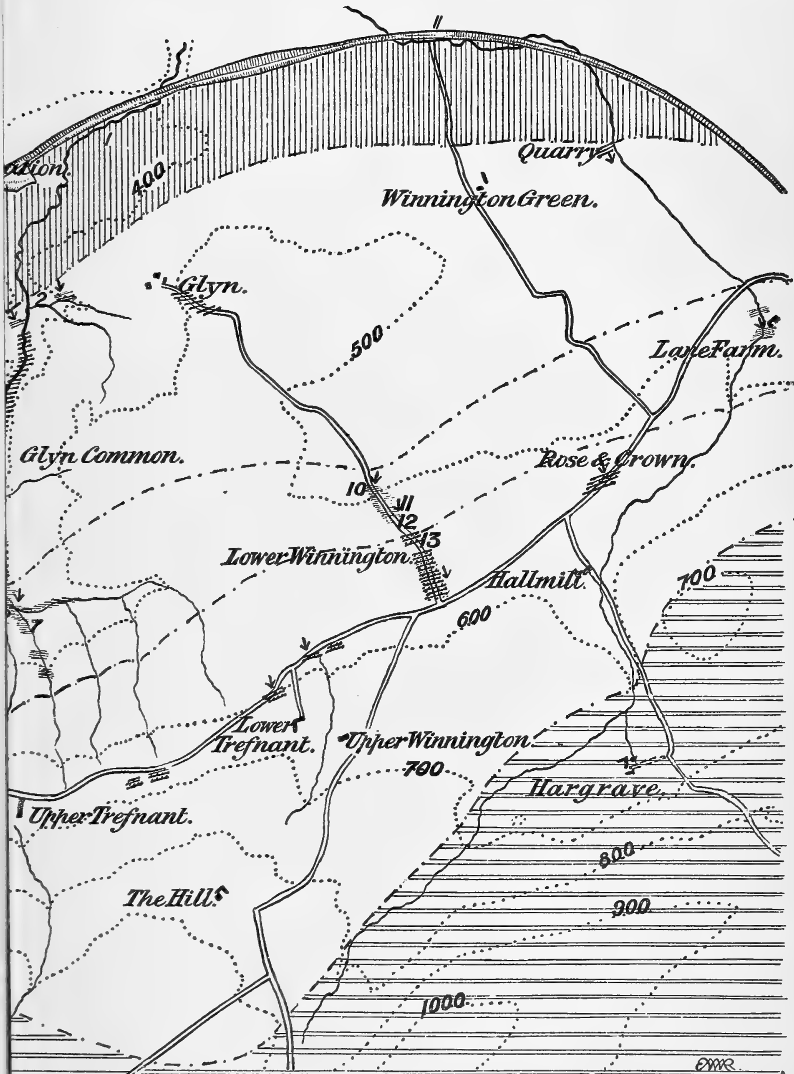
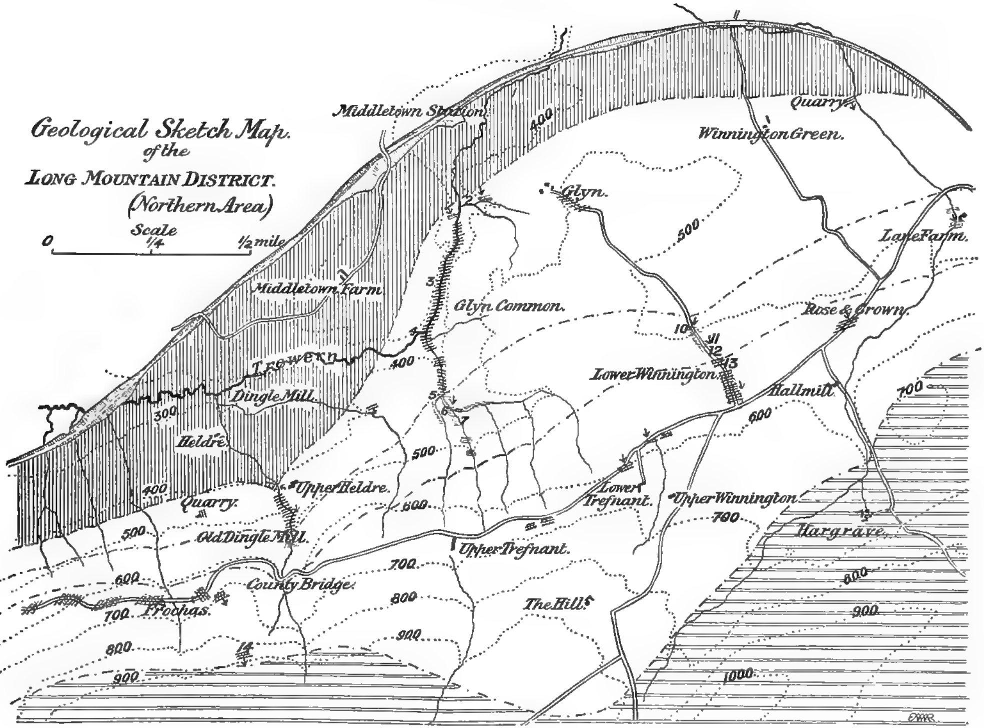


ation.
400
Quarry.
Winnington Green.
Glyn.
500
Lane Farm.
Glyn Common.
Rose & Crown.
10
11
12
13
Lower Winnington.
Hallmill.
700
600
Lower
Trefnant.
Upper Winnington.
700
Hargrave.
Upper Trefnant.
800
The Hill.
900
1000


Geological Sketch Map
of the
LONG MOUNTAIN DISTRICT.
(Northern Area)
Scale
0
1/4
1/2 mile
Middletown Station
400
Quarry
Winnington Green.
Glyn.
500
Lane Farm.
Middletown Farm.
Glyn Common.
Rose & Crown.
10
11
12
13
Lower Winnington.
Leowern
400
Dingle Mill.
Hallmill
700
300
600
Heldre.
500
Upper Heldre.
Lower Trefnant.
Upper Winnington
400
Quarry.
600
700
Hargrave.
500
Old Dingle Mill.
Upper Trefnant.
600
County Bridge.
700
800
700
Frochas.
800
The Hill.
900
800
900
900
1000
14
1
2
3
4
5
6
7
15

Figs. 23 & 24. *M. uncinatus*, var. *orbatus* nov. 23 A, B. Trefnant-Middletown Brook (Loc. 5 in Pl. XXVI).
24. Var. *micropoma* (Jækel). 24 A. Elton-Ludlow Road. 24 B. Road above Garbett's Hall, Long Mountain.

Fig. 25. *M. scanicus*, Tullb. 25 A. Aberedw Hill (Loc. 7 in fig. 6, p. 435). 25 B. Aberedw Hill (Loc. 3 in fig. 6).
26. *M. crinitus*, sp. nov. Lower Winnington Lane, Long Mountain.
27. *M. bohemicus* (Barr.). 27 A. River Irfon, Builth. 27 B. Aberedw Hill.
28. *M. Nilssoni* (Barr.). 28 A. Adferton. Coll. J. Hopkinson. 28 B. Elton-Evenhay Lane.
29. *Retiolites spinosus*, sp. nov. Vicarage Road, Builth (Loc. c′ in fig. 5, p. 432).
30. *Retiolites (Gothograptus) nassa*, Holm. Borek, Bohemia.

Plate XXVI.

Geological Sketch-map of the Long Mountain District (Northern Area) on the scale of 3 inches to the mile.

Discussion.

Mr. Hopkinson said that, although he had worked out the zonal distribution of the graptolites of the Lower Ludlow rocks in the neighbourhood of Ludlow, and had communicated two papers on the subject to the British Association, also describing and figuring several new species in La Touche's 'Geology of Shropshire,' he had not been able, in the few short visits which he had paid to the district, to arrive at results which he considered worthy of being brought before the Society; and he was pleased to find that what he had failed to do was accomplished by the Authoress. He could assign an approximate position in the Ludlow mudstones to a few species wherever collected in that area, but there were certain difficulties which he had been unable to overcome. In the first place, it was necessary to confirm the results from this area by working out the zonal distribution in other areas; then there was the difficulty of being certain as to the identification of some of Barrande's species, which could only be overcome, as it had been by the Authoress, by an actual examination of Barrande's specimens; and, lastly, he had been unable to determine the precise horizon of the Cladophora found at Bow Bridge near Downton, and, so far as he knew, nowhere else in the Lower Ludlow rocks in this country. It was stated in the paper that *Monograptus* was the only genus represented, but that was the case only so far as the Rhabdophora are concerned, for here were found species of *Callograptus*, *Dendrograptus*, and *Ptilograptus*. He thought that this Cladophora-bed was just below the zone of *Monograptus leintwardinensis*—that is, nearly at the top of the Lower Ludlow. He had found a fragment of a graptolite above Aymestry Limestone, but he could not be certain that it was above the Aymestry Limestone, for the shale in which he found it may have been between the two beds of limestone, the upper bed not showing. It was certainly the fact that the beds became more calcareous as the summit of the

mudstone was approached, but their more arenaceous character was equally well marked.

The Rev. J. F. Blake said that he was convinced of the extreme importance of the subdivision of the great unvarying masses of the Lower Ludlow, particularly in the typical districts; but he could not help being somewhat sceptical as to the naming of graptolites in general. They preserved so few characters, and these appeared to be so liable to be masked by accidents of preservation, while the writers on the group did not seem to have made up their minds as to the relative value of the characters.

Prof. Watts congratulated the Authoress on the good work done. As he had previously worked in one of the districts alluded to, the Long Mountain, he believed that the Authoress was right in her classification. He drew attention to the admirable illustrations which accompanied the paper.

Mr. C. D. Sherborn also spoke.

Prof. Lapworth pointed out the great interest of this paper, as showing for the first time that the principle of zonal mapping by means of graptolites is applicable even in the very latest formation in which the Rhabdophora have hitherto been certainly recognized; and, further, that this zonal method of stratigraphy not only enables us to correct the previously published maps of the Silurian rocks of the Welsh Borderland, but affords us a means of mapping the monotonous flaggy and mudstone series of all Eastern Wales in detail in the future, and of bringing them into direct comparison with the corresponding strata of other districts. The main obstacle which had formerly stood in the way of the graptolithologist who attempted the study of these Lower Ludlow graptolites, was the uncertainty of the identity of many of our British forms with the Bohemian species originally described in the classical works of Barrande. Thanks to the detailed revision of the Bohemian graptolites recently published by Dr. Perner, and to the fact that the Authoress and Miss Elles, previous to the commencement of their investigations, paid a visit to Bohemia, examined Barrande's types in the Prague Museum, and, guided by Dr. Perner, collected many of the critical forms in the field, we have now a guarantee that the identifications may be regarded as reliable. Mr. Hopkinson's work among the Ludlow graptolites had long been recognized as the most important hitherto accomplished among these rocks. The Authoress had found it of the highest value in her own work, and had described and figured specimens of the Rhabdophora from his collection among her types. Too little is as yet known of the Cladophora to make them available for zonal purposes.

As respects Prof. Blake's observations on the ammonites and graptolites, it was but natural that the students of the one group should find themselves unable to appreciate the minute distinctions relied upon by the students of the other, or the necessity for the very detailed classifications insisted upon. But the specific forms in both groups are certainly of high stratigraphical value, and no doubt all disputes and difficulties will disappear in the course of time.

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Vol. LVI. AUGUST 10th, 1900. **No. 223.**
PART 3.

C. A. White

THE

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OF THE

GEOLOGICAL SOCIETY.

EDITED BY

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[With Ten Plates, illustrating Papers by Mr. F. Rutley, Dr. C. Callaway, Messrs. J. B. Hill & H. Kynaston, Mr. F. Chapman, Mr. A. K. Coomára-Swámy, Mr. H. H. Thomas, and Prof. H. G. Seeley.]

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SESSION 1900–1901.

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,,	December	5–19

1901.

,,	January	9–23
,,	February (*Anniversary*, Feb. 15th)	6–20
,,	March	6–20
,,	April	3–24
,,	May	8–22
,,	June	5–19

[*Business will commence at Eight o'Clock precisely each Evening.*]

25. Additional Notes on some Eruptive Rocks from New Zealand.

By Frank Rutley, Esq., F.G.S. (Read April 4th, 1900.)

[Plate XXVII.]

The rocks described in this paper were, with two or three exceptions, collected by Mr. James Park, F.G.S., and reached me just before the completion of the paper on the rhyolites of the Hauraki Goldfields, read last year before this Society.[1] A few of these specimens came from the area dealt with in that paper, but a considerable number of them are from other localities in the North Island, including several from Rotorua, which are interesting as affording recent examples of solfataric action.

For the estimations of the total silica in these rocks I have to thank my friend Mr. Philip Holland, F.I.C., F.C.S., by whom they were made. Lantern-slides of some of the more typical rock-sections have been very kindly prepared for me by Mr. Frederick Chapman, A.L.S., F.R.M.S., of the Royal College of Science, South Kensington.

The present paper may, to some extent, be regarded as a continuation of that on the Hauraki rhyolites, but although certain specimens, about to be described, bear a tolerably close resemblance to some of those dealt with in the last paper, many of them, when examined microscopically, are found to present points of interest which render them worthy of special notice.

These rocks vary so much in their structural details that no attempt will be made to adopt any systematic order in their description, except that the specimens from Rotorua will be treated consecutively at the end of the paper.

H_{21}. Waihi.—A pale-grey, lithoidal rhyolite, with little dark-green crystals suggestive of pyroxene, and small colourless crystals of felspar.

Under the microscope the rock is seen to be a rhyolite with an irregularly-undulating fluxion-banding, the lithoidal character being due to the development partly of globulites, partly of spherulitic growths. The latter are best seen in ordinary transmitted light, when magnified about 150 diameters. Between crossed nicols the spherulitic structure is very obscure and, owing to the bright illumination of only a few fibres or rods in each spherulite, gives rise to the appearance of a rather sparse dissemination of microlites through a partly isotropic groundmass. Small porphyritic crystals and fragments of augite are present in the rock. The prismatic angle, measured in a section normal to the vertical axis of one of these crystals, was 87°. The augites are more or less corroded.

[1] 'Notes on the Rhyolites of the Hauraki Goldfields' by J. Park & F. Rutley, with Chemical Analyses by P. Holland, Quart. Journ. Geol. Soc. vol. lv (1899) p. 449.

Porphyritic crystals and fragments of felspar also occur. These, from their extinction-angles, may, in some cases, be referred to sanidine, in others to andesine. The section also contains small crystals and grains of magnetite and some limonite, the latter probably pseudomorphous after pyrites. Ilmenite may likewise be present in small quantity, but the evidence upon this point is unsatisfactory.

H_{22}. Waihi.—The specimen shows conchoidal fracture, and is scratched with difficulty by a knife-blade. It is dark brown, and has a resinous lustre, but there are paler spots and markings upon which the resinous lustre is absent. The rock has the general appearance of ordinary semi-opal.

Under the microscope, in ordinary transmitted light, the section varies from nearly colourless to pale yellow, and in places is almost orange-yellow, with deep brown spots which sometimes are surrounded by annular borders of like colour but slightly separated from the nuclear spots. Only parts of the section appear to be isotropic when viewed between crossed nicols, a considerable portion of it being traversed by irregularly-reticulating, anisotropic streaks, which vaguely suggest the possibility of an original vegetable structure.

Since the label, forwarded with the specimen, states that it occurred in rhyolite, it may possibly have been a fragment of silicified wood,[1] taken up and more or less altered by a lava-stream. Dr. G. J. Hinde, F.R.S., to whom I submitted the section, kindly examined it and, while reserving any definite opinion upon it, favoured me with a letter, from which the following statements are extracted:—

'I feel much doubt whether any wood structure is now shown in it. Whether it may have been wood originally, and has had the structure destroyed, is another question; but considering the very perfect preservation of the structure in fossilized wood, I do not think that such has been the case with this specimen.'

He further adds,

'I do not see how wood is likely to have been preserved if caught up and enveloped in a recent condition by a lava-flow; it might possibly not be destroyed if it were at the time silicified.'

H_{23}. Water-race, Waihi.—A pale pinkish-grey rock, containing dark-grey angular fragments, ranging from almost microscopic dimensions to more than an inch in diameter.

The rock is seen under the microscope to be a pumiceous rhyolite-tuff containing crystals of plagioclastic felspars, mostly oligoclase and andesine. Quartz and biotite are present in small quantity. The section shows one fragment of quartz which has been cracked into three pieces. They have been slightly separated, and the middle one somewhat displaced, so that it has a different orientation from that of the two terminal portions. A fragment of

[1] In Hochstetter's 'New Zealand' (1863) transl. E. Sauter (Stuttgart, 1867), it is stated on p. 119 that silicified wood occurs 'in the creeks in many localities where siliceous rocks are decomposing.'

a porphyritic felspar-crystal shows zonal banding in polarized light, and the extinction-angles of the twin lamellæ indicate that it is bytownite. The pumiceous portions of this section show the characteristic fibrous structure, which is, however, sometimes hard to distinguish from the fluxion-banding of rhyolitic lavas. Apart from the fragments of crystals, the general mass of the rock is isotropic.

H_{24}. Tauranga Bridge.—A pale pinkish-grey rock with minute crystals of glassy lustre, small dark specks, and pale fibrous-looking fragments.

In thin section the rock is seen, under the microscope, to be essentially a pumice-tuff, containing a few small fragments, apparently of andesite, fragments of plagioclastic felspar, corroded quartz, with small sporadic scales of biotite and specks of pyrites.

H_{25}. Tahua, Mayor or Obsidian Island.—A black obsidian, appearing as a very pale brownish glass on thin edges, and showing very perfect conchoidal fracture.

Under the microscope, the section is seen to contain numerous gas-inclusions, often elongated and of very irregular shape, sometimes sharply angular in form, at others oval or fusiform. A few colourless microlites, which for the most part give approximately straight or very low extinction-angles, are no doubt felspars. There are also a few very pale-green microlites, which in some instances give an extinction-angle of 19° to the direction of elongation. The latter appear to be extremely narrow in proportion to their length.

Prof. F. W. Hutton [1] has described an obsidian from this locality, in which he detected similar hornblende-microlites, and adds that there are 'no trichites nor microvesicles.' He also describes a reddish-brown pitchstone from Mayor Island, which exhibits a pumiceous character.

H_{26}. Tahua or Mayor Island.—A black obsidian with some small greyish-white specks. It has a less marked conchoidal fracture and a less perfect vitreous lustre than the preceding specimen. This is due to the presence of the very numerous gas-pores, which, with a pocket-lens, may be seen pitting the fractured surfaces.

Under the microscope these gas-inclusions are seen to vary greatly in form and dimensions, and it is only here and there that, when fusiform or tubular, they indicate the direction of flow (Pl. XXVII, fig. 1). Very small crystals, mostly mere microlites of felspar, are plentiful in this section. They sometimes form little aggregates, which are apparently the white specks visible in the hand-specimen. There are also many microlites of hornblende present: these occasionally show extinction-angles up to 19° or more with the axis of elongation. The section also shows part of a pyroxene-crystal,

[1] 'The Eruptive Rocks of New Zealand' Journ. Roy. Soc. N.S.W. vol. xxiii (1889) p. 121.

which, in convergent polarized light, gives a partial biaxial interference-figure of positive sign.

H_{27}. Waitekauri.—A bluish-grey vitreous rock, much resembling some of the perlitic rocks of Schemnitz in Hungary. Under the microscope there is no apparent fluxion-banding, and (with the exception of eyelash-like trichites) the glassy matter is almost wholly free from microlites; but numerous porphyritic crystals of felspar, mostly sanidine or oligoclase, quartz often corroded, biotite, and occasional small specks of magnetite, are present.

The perlicity of this section is extremely well-defined, and is remarkable as serving, in certain spots, to illustrate the transition from straight to curvilinear cracks. As pointed out many years ago,[1] the curvilinear perlitic cracks are almost invariably packed between straight or approximately straight fissures, and are not traversed by the latter.

In parts of this section cracks may be seen spanning transversely the areas between rudely parallel and comparatively straight fissures. These transverse cracks are, in some cases, almost straight, while in other instances they show a distinct tendency to describe perlitic curves. When this is the case, the perlitic bodies are elongated between the rungs of the ladder-like systems of cracks, as shown in Pl. XXVII, fig. 2. Such a scalariform perlicity has, so far as I am aware, not hitherto been noticed.

The rock, apart from its porphyritic crystals and its fissures, is remarkably isotropic.

Mr. Philip Holland has kindly estimated the silica in this rock. It amounts to 73·45 per cent. This sets at rest any doubt about the rock being an obsidian, the Hungarian perlitic rocks, which this somewhat resembles, being in many cases hyalodacites, which are characterized by a lower percentage of silica.

H_{28}. Waitekauri.—Apparently a breccia composed of dark-grey, yellowish-brown, and white fragments. The rock is generally very dark, even black in parts, with a granulated appearance and with small dark specks which have a vitreous lustre, the specimen slightly resembling a fine-grained schorlaceous rock.

Under the microscope the smaller fragments are seen to be felspar, mostly andesine and labradorite. There are often, however, crystals of sanidine, some of them twinned on the Carlsbad type and, in one instance, on the Baveno type. Occasionally the plagioclastic felspars show zonal banding, the extinction-angles indicating that the outer zone is andesine, while the inner portion is labradorite. Crystals of augite and of a rhombic pyroxene, as well as pyrites, occur in this section, together with fragments of andesite and rhyolite, the latter sometimes spherulitic. These spherulites are of the brown, microfelsitic kind. All these fragments of rocks

[1] 'On some Structures in Obsidian, Perlite, & Leucite' Monthly Microsc. Journ. vol. xv (1876) pp. 179 *et seqq.* & pl. cxxxiv.

and minerals are embedded in rhyolite, the fluxion-banding of which sweeps around them.

Everything seems to indicate that the rock is a tufaceous rhyolitic lava, which has either taken up fragments of andesite and rhyolite in its lower portion, or else has been erupted during a shower of lapilli upon its surface. The rhyolite of the lava-stream is practically isotropic.

H_{29}. Waitekauri.—A brown semi-vitreous rock, with small dark and light crystals or fragments: the groundmass, where weathered, appearing pale-grey, with small white and brown crystals.

Under the microscope, this is seen to be a rhyolite with a damascened or corrugated fluxion-banding, and containing many crystals and fragments of felspars—chiefly oligoclase and andesine, augite, rhombic pyroxene, olivine, and pyrites. The marked difference between the unweathered and the weathered portions of the hand-specimen is not very clearly seen in the section when it is viewed in ordinary transmitted light; but in reflected light it is found to be due to a selective alteration (kaolinization) of certain streaks, so that, in the most weathered part of the rock, a very large amount of kaolin is present: while in the comparatively unweathered part much less opaque white matter is visible, since only a limited portion of the fluxion-banding has been kaolinized. This clearly shows that certain bands in a rhyolite may be more readily attacked by atmospheric agency than others, not necessarily because they differ in chemical composition, although some slight differences may exist, as pointed out by Prof. Iddings [1]; but rather because it may often be noted that there are differences in grain or texture in the alternating fluxion-bands. It seems only reasonable to infer that the same kind of difference in solubility would exist between such bands as exists in the solubility of any mineral substance when coarsely and finely powdered.

The rock may be called a tufaceous rhyolite. The crystals and fragments in it have evidently been derived from andesites which occupy a considerable tract north of Waitekauri.[2]

H_{30}. Mataura.—A pale-grey rock, with very delicate banding, and showing small colourless scales. It is sufficiently hard to resist the point of a penknife.

A section of this rock, when examined under the microscope, does not seem to present any distinct characters suggestive of a lava, but rather those of a laminated tuff, composed of exceedingly fine volcanic dust in which a considerable amount of tridymite occurs, mostly in irregularly-segregated plates, forming bands and patches. Where free from tridymite the section is nearly isotropic. It appears to be a much-altered rhyolitic tuff. Microscopically it bears some resemblance to certain earthy volcanic tuffs met with

[1] 'Obsidian Cliff' 7th Ann. Rep. U.S. Geol. Surv. 1885–86 [1888] p. 274.
[2] See map of the Hauraki Goldfields, by James Park, Quart. Journ. Geol. Soc. vol. lv (1899) pl. xxxi.

in Auvergne. The section contains numerous colourless microlites and a few crystals of sanidine, also some opaque white matter forming small pseudomorphs after a mineral which appears to have crystallized in approximately octahedral forms. In one instance a fragment of an opaque black mineral is surrounded by a thin opaque white crust. This may possibly represent a superficial alteration of ilmenite into leucoxene.

Small fragments of rock are present, but not plentiful, in this section. They are so much altered that it is unsafe to express any opinion about them other than that they seem, for the most part, to have been derived from rhyolites.

The great hardness of the rock is to be attributed to the tridymite with which it is so abundantly impregnated.

H_{31}. Waihi Beach ('older rhyolite' of Park).—A pale greyish-white spherulitic rock, containing small dark specks and colourless crystals with a vitreous lustre, also a few dark micaceous-looking scales. The spherulites range from about $\frac{1}{8}$ inch in diameter to smaller dimensions.

Under the microscope, the rock appears to consist almost wholly of spherulites which seem originally to have been of the brown microfelsitic type. They are still brown, but are almost isotropic, in the centres perfectly so, but the peripheral portions usually transmit light very feebly between crossed nicols.

The spherulites often have polygonal boundaries, as though they had pressed against one another, and among them occur numerous porphyritic crystals and fragments of crystals, frequently showing very distinct evidence of corrosion. These porphyritic crystals may be recognized as quartz, felspars, biotite, and pyrites. The quartz appears to have been cracked and affected by heat. The felspars are all practically isotropic, and can consequently be identified by the forms of their sections alone. Biotite is not very plentiful in this rock: basal sections may be recognized by the approximately hexagonal forms giving angles of 60°, but in convergent polarized light no satisfactory interference-figure can be seen, since the crystals are rendered more or less opaque by partial alteration into limonite. One section transverse to the cleavage shows the characteristic pleochroism and absorption. The pyrites occurs in cubes, groups of cubes, and irregularly-shaped patches. The section is speckled by diminutive opaque crystals, many of which appear to be magnetite or pseudomorphs after that mineral.

One of the most interesting features of this section is, however, to be found in a small irregular area in which a coarse mosaic of felspar and quartz may be seen between crossed nicols. In convergent light the quartz shows partial uniaxial interference-figures, and, in one or two instances, a positive sign. The felspars also show partial interference-figures, a dark, curved brush sweeping diagonally across the field. This area in the section is, therefore, unquestionably felsite, so far as mineral constitution is concerned. Structurally it differs from an ordinary felsite in the circumstance

that there is a little nearly isotropic matter present among the grains of quartz and felspar: the seemingly isotropic matter being seen under a higher power (140 diameters) to be filled with globulites and margarites, and to show very decided double refraction in places.

These apparently isotropic patches are not really so, but are diminutive fragments, evidently derived from the spherulites which bound this felsitic area. In order to prove that this is the case, one has only to examine the margin of this small area, when it will be seen that those parts of the spherulites abutting on it are gnawed away and disintegrated along the fibration of the spherules in the most irregular manner. Small pieces of the spherules have become detached and taken up in the felsitic matter, and the latter, moreover, may be seen occupying peripheral parts of spherules which, where they remain intact, are almost devoid of double refraction. Nearly in the middle of this felsitic area may be seen, in ordinary transmitted light, a well-defined circle, from the centre of which as though traced by fine pen-strokes, radial markings are partly outlined. In polarized light, this 'sketch of a spherulite' breaks up into a number of irregular patches or grains, which constitute part of the surrounding felsite. (See Pl. XXVII, figs. 3 & 4.)

If we endeavour to realize the various changes through which this small portion of the rock has passed before reaching its present condition, we have to consider:

(1) The rise and outpouring of a rhyolitic magma containing numerous already-formed crystals of felspar, quartz, etc., some entire, others broken, which are undergoing a process of superficial corrosion;
(2) As this lava solidifies rapidly, it becomes a glass or obsidian, containing the porphyritic crystals and fragments of earlier generation;
(3) At a subsequent period the glass becomes devitrified by the development of globulites and other microscopic bodies, and by the formation of spherulites, which originate at numerous points, incorporating in their growth a certain amount of the devitrified glass. These from their brown colour, their dimensions, and from the prevalence of globulites in them, may (from comparison with sections of similar rocks from the district) be presumed to have been microfelsite-spherulites. Doubtless, when first formed they would have exhibited such double refraction as spherulites of this kind are generally found to possess, and, as they continued to increase in size, the growth of their radiating fibres would become arrested by those of adjacent spherulites, in some cases along planes tangential to the mutually-approaching spheres, thus giving rise to the polygonal forms which the spherulites sometimes assume;
(4) Conditions supervened, such as may be accounted for in any active volcanic district, which resulted in this solidified spherulitic rock being again raised to a high temperature, one sufficiently high to deprive of their double refraction, not merely the spherulites, but also the earlier-formed fragments and crystals of felspar;
(5) The high temperature resulting from this secondary heating, probably assisted by water holding alkaline salts and other mineral matter in solution, appears to have further acted upon certain parts of the rock, probably along joints or on the walls of small cavities, thus decomposing and disintegrating the spherulites: such portions, on slow cooling, assuming the structural character of a coarse-grained felsite, while also possessing the mineral constitution of such a rock.

It appears that, in this case, the changes are mainly molecular,

leading, in an extreme phase, to the obliteration of original structure and the ultimate development of a felsitic condition.

If such changes can be brought about in a rhyolitic lava of Tertiary age, little wonder can be felt at the occurrence of like changes in rhyolites of great geological antiquity. It even seems possible, if not probable, that some of the felsites which now yield no microscopic evidence that they were ever lavas, may originally have possessed structures which, had they been preserved, would have completely set at rest all doubt about their origin.

H_{32}. Waihi Monument ('older rhyolite' of Park).—A yellowish rock with a spherulitic structure, and containing some small dark-green plates which are easily scratched : these appear to be chlorite pseudomorphous after biotite. The spherulites average between $\frac{1}{16}$ and $\frac{1}{8}$ inch in diameter.

Under the microscope, this appears to be a comparatively fresh or very slightly altered representative of the preceding rock from Waihi Beach (H_{31}). The spherulites, of which the rock is almost entirely composed, are, however, quite as doubly refracting as those that occur in the rocks of Omahu and Mercury Bay.

Very small black crystals and specks are common throughout the section. In most instances these may be regarded as magnetite. In reflected light no distinct evidence of the presence of pyrites can be detected.

The spherulites are often packed closely together, but when spaces exist between them, those spaces are filled with a colourless substance containing numerous microlites, which in most cases are colourless and give approximately straight extinctions. The colourless matter in which they lie is more or less isotropic, and mainly consists of scales, apparently of tridymite, with possibly some microfelsite.

The section contains a few porphyritic felspar-crystals, the largest measuring over $\frac{3}{8}$ inch in length. They contain many glass-inclusions, often show twin lamellæ, and appear in many instances to be labradorite. Some of them are much corroded. One of the largest porphyritic crystals gives an extinction-angle of 38°, and the partial interference-figure seen in convergent polarized light indicates the oblique emergence of one of the optic axes just outside the field. This may, therefore, be regarded as a section of anorthite parallel to the brachypinacoid. The crystal is traversed by irregular cracks, and contains many glass-inclusions.

The rock may be called a rhyolite, or preferably an obsidian, composed of microfelsitic spherulites with some porphyritic crystals of felspar.

H_{33}. Waihi Beach.—A pale greenish-white rock with darker green mottling, containing a few small, micaceous-looking plates, and numerous little grains which have a vitreous lustre and occasionally show conchoidal fracture. The specimen is so hard that the point of a knife-blade barely makes any appreciable streak.

Under the microscope the rock is seen to be a perlitic rhyolite, pervaded by a small and rather ill-defined spherulitic structure. There are also much larger spherulites sometimes forming aggregates. The double refraction of these larger spherulites is seen, when tested with *teinte sensible* No. 2, to be positive, but the cross is often so broken up and distorted that it is then difficult to ascertain their optical sign with any certainty. The character of the smaller spherulites is still more difficult to recognize, but they also appear to be positive.

Cracked and corroded crystals and angular fragments of quartz are plentiful in this section, and there are also some porphyritic crystals of felspar: some of these being sanidine, others apparently andesine, the former preponderating. Porphyritic crystals of biotite also occur, often well-developed, but not very numerous. The green colour of the rock is probably due to the fine dust and microlites which pervade it. The latter extinguish parallel to their length, and are probably epidote.

Rocks from Rotorua.

In the Ninth Annual Report of the United States Geological Survey, 1887–88 [1889], there is a treatise on the 'Formation of Travertine & Siliceous Sinter by the Vegetation of Hot Springs' by W. H. Weed, in which, after dealing very fully with the subject in its relation to the geysers and hot springs of the United States, some details are added concerning his examination of specimens of siliceous sinter from New Zealand. He states (*op. cit.* p. 673) that

'The siliceous sinters from Rotorua vary from pulverulent deposits of impure silica to dense, white opal sinters. Two of the specimens were evidently formed about spouting vents, showing the peculiar structure and beaded surface produced by the evaporation of spattered drops of water. Such sinters, to which the name of geyserite may be most properly applied, are very common about the Yellowstone geysers, occurring often in beautiful coralloidal forms, sometimes possessing a bright pearly lustre. The New Zealand specimens are parts of an old deposit formed in this way, and consist of numerous little pillars formed of many convex layers of pink and white silica, resembling a pile of minute caps, one upon another. This geyserite is wholly the result of evaporation, which adds film after film of glassy silica to the surface of the deposit, as often as wet by the steam or spray from the geyser.'

Mr. Weed further states (*op. cit.* p. 674) that

'Two of the specimens are of especial interest because their structure indicates that the algous life of the hot waters of Rotorua produced siliceous sinter.'

It appears, however, from comparison of this statement with that previously quoted, that the siliceous sinters of Rotorua can be formed without organic aid as well as with it. That Mr. Weed also regards the question of the deposition of these sinters from both points of view, is seen when he proceeds to say (*op. cit.* p. 676):

'No information is obtainable relative to the comparative abundance of the different types of sinter, but the presence of acid, and comparative scarcity of alkaline waters shown by the list of springs published by Dr. Hector, leads to

the belief that algous sinter forms a smaller proportion of the siliceous deposits than it does at most of the geyser-basins of the Yellowstone, where the waters are chiefly alkaline.'

Mr. Weed gives a brief account of the microscopic characters of some of the siliceous sinters of the Yellowstone, but remarks:

'Thin sections of siliceous sinters fail to show the origin and nature of the deposit as clearly as had been hoped';

and again (*op. cit.* p. 667),

'If many of the algous sinters fail to reveal an organic structure beneath the microscope, they are nevertheless easily distinguished from the more glassy and pearly sinters formed by evaporation.'

Again (*op. cit.* pp. 671-72),

'The physical differences in the unaltered sinters formed by evaporation and those of algous origin is generally quite marked, the former being translucent or vitreous, hard, and heavy, while the algous sinter is opaque, white, and often chalk-like in appearance.'

The description given by F. von Hochstetter regarding the deposit formed by one of the hot springs on the Waikato is also of interest, as it is applicable to some of the specimens about to be described. He states that the deposit, like that of all the other springs near the Waikato, is siliceous, that, when recent,

'It is soft as gelatine, gradually hardening into a triturable mass, sandy to the touch, and finally forming, by the layers deposited one above the other, a solid mass of rock of a very variable description at different places, both as to colour and structure. Here it is a radiated fibrous or stalky mass of light-brown colour; there a chalcedony hard as steel, or a grey flint; at other places the deposit is white, with glossy conchoidal fracture like milk-opal, or with earthy fracture like magnesite.'[1]

With these prefatory quotations, I may now proceed to describe some of the rocks from Rotorua, chiefly collected by Mr. James Park.

H_{38}. Rotorua.—A bluish-grey rock, with feebly vitreous lustre and subconchoidal fracture. The specimen somewhat resembles a pale-grey pitchstone, and shows, where weathered, a whitish pulverulent crust.

Under the microscope, the rock is seen to consist of small fragments of pumice, with a considerable sprinkling of minute fragments of felspar and an occasional grain of quartz. Some of the felspar-fragments show lamellar twinning and may be referred to andesine, but sanidine and oligoclase are also present. Viewed between crossed nicols, the section is seen to contain some perfectly isotropic matter which consists partly of pumice and partly of a cement of amorphous silica, while some feebly or partly anisotropic matter also helps to form the cement. In parts it is brown in ordinary transmitted light, while in reflected light it appears pink.

The rock is essentially a pumice-tuff, cemented and indurated by silica derived from the hot springs so prevalent in the district.

[1] 'New Zealand' transl. E. Sauter (Stuttgart, 1867) p. 398.

The silica in this rock, when powdered and dried at 100° C., has been found by Mr. Philip Holland to amount to 81·99 per cent.

H_{39}. Rotorua.—A dark-grey rock with weak vitreous lustre, having dull pinkish-white patches and mottlings. The darker portion of the specimen shows small, irregularly-shaped cavities, and in colour, lustre, and fracture somewhat resembles a baked slate or porcellanite.

Under the microscope it is seen to be a fine pumiceous tuff, cemented by siliceous sinter or geyserite. The fragments of pumice are for the most part extremely small, little more than pumice-dust, but the section contains some larger fragments. The finely shredded pumice-fragments are suggestive of Mugge's bogenstruktur, or what Lane describes as 'concave ash.'[1] A few fragments of felspar are present. Mr. Holland has kindly estimated the silica in this specimen, and finds that it amounts to 81·22 per cent., the rock having previously been powdered, and the powder dried at 100° C.

The geyserite, which constitutes a considerable portion of the rock, is not perfectly isotropic, but feebly transmits a milky bluish-white light between crossed nicols. This is also to be noticed in a section taken from a specimen of Icelandic geyserite,[2] which has a weak milky appearance where the section is thin, but where thicker or less translucent the appearance is almost snow-white.[3] That the milky or snow-white aspect between crossed nicols is due to transmitted polarized light may be demonstrated :

(*a*) By cutting off all extraneous light which could be reflected from the upper surface of the section, when its aspect remains unaltered ;
(*b*) By placing the principal sections of the nicols parallel, when the appearance closely resembles that seen when ordinary transmitted light is employed ;
(*c*) By using ordinary reflected light, the section having then nearly the same appearance as when viewed between crossed nicols.

H_{40}. Rotorua.—A white to yellowish-white siliceous deposit with a conchoidal fracture, and in most parts showing a waxy lustre, in other parts dull and pulverulent.

Under the microscope, the section exhibits a rough and somewhat irregularly-banded structure. The different bands vary in character, some appearing like vitreous matter speckled with small translucent bodies, at first sight suggestive of globulites, but they are not spherical as a rule. In other bands these small bodies are so densely packed that the bands are far less translucent. Some of the darker bands seem to have been rendered quite spongy through the presence of numerous irregular cavities, now filled with colourless doubly-refracting matter which, on rotation between crossed nicols, appears to be hyalite : the globular forms which line the

[1] 'Geological Report on Isle Royale' by Alfred C. Lane, Geol. Surv. Mich. vol. vi, pt. i (1898) pp. 168, 171, 175.

[2] The specimen is one of several collected by Mr. G. F. Rodwell, to whose generosity I am indebted for these and other Icelandic specimens.

[3] A very similar appearance is also to be noted in some devitrified obsidians, when viewed in reflected light.

walls of some of these cavities renders such an assumption more than probable. The optical character of the substance almost wholly constituting this section agrees perfectly with that previously described as characteristic of geyserite. This specimen indeed seems to be a remarkably pure example, since after powdering and drying it at 100° C., Mr. Philip Holland found the percentage of silica to be 93·59. Some idea of the probable nature of the other constituents may be gathered from an analysis, by J. W. Mallet, of a siliceous deposit from the hot springs of Lake Taupa :[1]

	Per cent.	
SiO_2	94·20	=99·86
Al_2O_3	1·58	
Fe_2O_3	0·17	
CaO	trace	
NaCl	0·85	
H_2O	3·06	

In one of the more translucent bands in this section there may be found evidence of diatoms, apparently similar to those commonly met with in deposits of tripoli. An amplification of about 250 diameters is, however, necessary before the existence of these small bodies can be recognized.

H_{41}. Rotorua.—A compact semi-opal, with waxy to sub-vitreous lustre and conchoidal fracture. It has a rude, irregularly-banded structure, one band being reddish-brown and the rest bluish-grey.

Under the microscope, the section is mainly isotropic between crossed nicols, and exhibits no appreciable structure. A few specks, apparently of pyrites, and numerous doubly-refracting grains, without any definite crystal-boundaries or cleavages, are present.

The reddish portions apparently owe their colour to hæmatite in a very fine state of division. A very obscure fibrous structure may be present in places.

H_{42}. Rotorua.—Rock consisting of white fragments, most of them apparently felspathic, embedded in a matrix or cement which is in part light bluish-grey and crystalline, in part dark or almost black. The specimen looks like a rather coarse breccia. On a cut surface, some of the white fragments show very small cavities, generally elongated and suggestive of irregular furrows.

Under the microscope, the section is seen to consist chiefly of lapilli of pumice, a few fragments of rock, possibly rhyolite, some of these being opaque and pink, others reddish-brown in transmitted light, and all more or less corroded superficially. There are also fragments of crystals, upon the original nature of which it is impossible to speculate, since they do not show definite crystal-boundaries or any cleavages: they are traversed by irregular cracks, and are practically isotropic. The section also contains a fragment of quartz. The whole of these fragments are bordered by hyalite, the remainder of the rock being filled in by isotropic silica

[1] Phil. Mag. vol. v (1853) p. 285; also quoted in Hochstetter's 'New Zealand' transl. E. Sauter (Stuttgart, 1867) p. 435.

or geyserite. (See Pl. XXVII, fig. 6.) Between crossed nicols the hyalite shows the usual double refraction due to tension, broken by an irregular series of dark brushes (parts of dark crosses). The contrast between the hyalite and the isotropic opal-silica is very marked.

H_{43}. Rotorua.—A brecciated rock resembling H_{42}, just described, but apparently more altered by solfataric action.

Under the microscope, the fragments which give the brecciated character to this rock are seen to be almost wholly pumice; still there are a few fragments in the section as to the nature of which there must be considerable doubt. Probably they are lapilli of rhyolite, very much honeycombed by the hydrothermal action to which they have been subjected. The cementing material is amorphous opal-silica. The fragments do not possess the broad hyalitic borders which surround the fragments in the rock previously described (H_{42}). The lapilli in the breccia, other than those of pumice, have evidently undergone considerable alteration, especially as regards their included crystals of felspar. The total percentage of silica present in this rock, after drying the powder at 100° C., has been estimated by Mr. Philip Holland as 87·89.

H_{44}. Rotorua.—A pink granular rock, easily rubbed to a very fine powder which feels harsh and gritty between the fingers.

Under the microscope, the section appears to consist mainly of extremely fine pumice-dust and amorphous silica, rendered porphyritic in aspect by lapilli of perlitic obsidian and pumice. The section is flecked by numerous irregular dots, patches, and sporadic irregular veins of a substance which in transmitted light seems nearly opaque and of a dark reddish-brown. When examined in reflected light, it is seen to be bright vermilion. The colour is more suggestive of cinnabar than hæmatite, but, when the substance is heated in a closed tube with dry carbonate of soda, no satisfactory evidence of the presence of mercury is to be detected. The suspicion that mercury might have been present was increased by the circumstance that cinnabar is sometimes found in connection with hot springs as a result of solfataric action,[1] and that its occurrence in New Zealand has already been noted.

The total percentage of silica in this rock, when powdered and dried at 100° C., was found by Mr. Holland to amount to 77·79. He also examined it for mercury, but failed to detect any; he found, however, 0·07 per cent. of organic matter.[2]

[1] Dana's 'System of Mineralogy' 6th ed. (1892) p. 67.

[2] Mr. Holland informs me that he treated a weighed portion of this rock with re-distilled and dry chloroform, and the filtered extract was colourless. The extract, on filtration and distillation, left a slight waxy residue which, heated over a flame on platinum-foil, gave off a resinous odour. The amount of this waxy matter was not more than 0·07 per cent., as stated above. Mr. Holland noted a similar odour on heating a paraffinoid substance, which he extracted some years ago by means of chloroform from black Scotch peat. He states that the pink colour of this sinter is due to ferric oxide.

H_{45}. Rotorua.—A grey to yellowish-white rock, with spherulitic structure, and showing in places a small amount of hyalite. The rock has a cavernous or honeycombed aspect due to solfataric action.[1]

Under the microscope this rock is seen to be an altered spherulitic obsidian, consisting almost entirely of spherulites of the large brown microfelsitic type, similar to those met with at Mercury Bay, except that these have undergone great change, while those of Mercury Bay are practically unaltered. The whole rock, indeed, appears to have been intensely affected by solfataric action. In many places the spherulites are partly, in others almost wholly bleached, the irregularly-shaped, brown, unaltered portions imparting an almost brecciated appearance to the section, when viewed in ordinary transmitted light.

The alteration of these spherulites is apparently of the same nature as that of the spherulites in the 'older rhyolite' of Waihi Beach (H_{31}) described on pp. 498–499 of this paper, but the change does not appear to have been carried quite so far as in the Waihi rock. The nature of the alteration seems to consist in the gradual substitution of silica for portions of the spherulites which have been dissolved: the process of molecular substitution having apparently gone on with great exactitude, as in the silicification of wood, the fibrous structure of the spherulites being beautifully preserved. (See Pl. XXVII, fig. 5.) An interesting feature of the change lies in the circumstance that, although the replacing substance was opal-silica, the altered parts of the spherulites exhibit the same double refraction between crossed nicols as those parts of the spherulites which remain brown and unaltered. The dark crosses pass through altered and unaltered parts of the spherulites without any appreciable break or modification. It seems possible that the mere fact of isotropic opal-silica replacing a fibrous structure suffices to impart double refraction, no matter whether the replaced fibre was anisotropic or not. Support is lent to this hypothesis by the feeble double refraction shown by fibres of glass ('spun glass'), the extinction taking place in the direction parallel to the length of the fibre. Again, in a section made from the white pulverulent crust on the surface of a specimen of silicified wood (wood-opal) from Tasmania, the fibrous structure of the woody tissue appears brilliantly illuminated when the fibres are placed at 45° to the principal sections of the crossed nicols, and becomes extinguished when these are turned parallel and at right angles to the length of the fibres. It is clear, therefore, that opal-silica, whether it replaces the fibres of woody tissue or the fibres of a spherulite, develops the phenomenon of double refraction.

The spaces between the spherulites in this Rotorua rock are filled with opal-silica. Where this has been deposited on the surface of a spherulite, it has often assumed the condition of hyalite, exhibiting,

[1] I am indebted for this specimen to the kindness of Mr. A. Vaughan Jennings, F.L.S., F.G.S., who procured it when visiting Rotorua in 1890.

in ordinary transmitted light, the mammillated surface, and, in polarized light, the double refraction characteristic of that variety of opal. Those parts of the section which lie between spherulites frequently contain some silica which is, as a rule, perfectly isotropic, save for a few bright doubly-refracting specks. In a few places in the section, some nearly opaque matter occurs. It usually forms thin irregular lines which have the appearance of lining cavities or filling cracks. In reflected light this substance has a rather strong pink colour, but concerning its nature or the pigment to which it owes its colour it seems unsafe to speculate. The silica-percentage of this rock is found by Mr. Philip Holland to be 75·90.

H_{46}. Rotorua.—Part of a dark-grey bomb, ejected during the eruption of Tarawera in 1886.[1] The form of this bomb was evidently all but spherical and, when entire, it measured probably between 2 and 3 inches in diameter.

Prof. A. P. W. Thomas, F.L.S., F.G.S., of University College, Auckland, has so well described the rock of which these bombs consist, that I cannot do better than quote his words:

'Under the microscope thin slices of the rock show rather numerous small crystals of felspar and yellowish augite. The felspars are mostly small and in ledge-shaped sections, but a few rather larger ones are present; they are nearly all plagioclases, but there are a few distinct sanidines. The augite is in small irregular crystals and granules. The groundmass of the rock is a grey glass with abundant crystallites (globulites, longulites, and microliths) of translucent substance, and grains of magnetite. Much of the augite should perhaps be considered as belonging to the groundmass.'[2]

To this description there seems nothing to add. The section now examined, although by no means so thin as could be wished, sufficiently confirms all that Prof. Thomas says. He further adds:

'Olivine was found in a few small crystals in some specimens, but as a rule it is quite absent.'

Discussing the precise character of the rock, he also says (*loc. cit.*):

'On account of the absence of olivine as an essential constituent, the presence of abundant glass with microliths, and of a little sanidine, the rock has been identified as an augite-andesite. Still, it must be admitted that the rock approximates to the basalts, as is further shown by its chemical analysis . . . The percentage of silica varies from 50·9 to 52·5, an amount which is lower than that usually found in augite-andesites, whilst it is not higher than that found in some basalts. But whether we call the rock an augite-andesite or a basalt without olivine, does not affect the results stated above, that the lava of the late eruption is basic, is new to the locality, and follows the acid rhyolites.'

From the resemblance which the section of this bomb bears to some of the Icelandic basalts without olivine, it seems probable that Prof. Thomas is perfectly justified in regarding the rock as a basalt.

[1] For this specimen I am indebted to Mr. G. F. Rodwell, who visited the scene of the eruption in 1887.

[2] 'Report on the Eruption of Tarawera & Rotomahana, N.Z.' (Wellington, 1888) p. 58.

The analyses of it, which he cites, made by Mr. J. A. Pond, Colonial Analyst, Auckland, are :—

	I. Per cent.	II. Per cent.	III. Per cent.
SiO_2	50·90	51·35	52·50
FeO & Fe_2O_3	14·10	14·50	12·70
Al_2O_3	20·00	18·20	18·20
CaO	10·38	10·26	11·05
MgO	2·77	3·10	4·65
Na_2O	·70	·835	·67
K_2O	·14	·16	·09
Cl	·04	·05	·05
SO_3	·22	·41	·32
P_2O_5	·16	·125	·06
Water and organic matter	·60	·60	—
CO_2	trace.	trace.	trace.
	100·01	99·59	100·29

I. Lapilli (augite-andesite), Wairoa.
II. " " " Pareheru.
III. " " " Eastern end of Rotoiti.

H_{47}. Rotorua.—A dark-grey to black obsidian, profusely speckled with yellowish-white crystalline or finely-granular spots.

Under the microscope, occasional porphyritic crystals of felspar are to be seen, sometimes entire, at others in fragments. For the most part they are sanidine, but there are also a few which show lamellar twinning and appear in one or two instances, from their extinction-angles, to be labradorite. The extinction in these felspars is often zonal, and they are more or less corroded and traversed by irregular cracks. Isolated dark-brown spherulites are also present in the section. These have occasionally been formed about a fragment of felspar. Some grains of magnetite occur, but they are not numerous. This obsidian is filled with globulites and longulites. One or two delicate, yellowish-brown, rod-like sections of crystals may be seen in this slide: their appearance suggests biotite, but they show inclined extinction and are probably hornblendes with a low extinction-angle of about 5°. A delicate fluxion-banding may be seen in some parts of the section.

Conclusions.

A consideration of the microscopic characters presented by the rhyolitic rocks of New Zealand, and of the alterations which they have experienced, especially through solfataric action, naturally leads to the enquiry whether the ancient rhyolites of Great Britain give evidence of similar changes.

We may, indeed, regard the rhyolitic lavas of New Zealand as one of the most recent text-books upon this subject, and it behoves geologists to make what use they can of such a source of information by endeavouring to ascertain whether our own old rhyolites can yield us some further clue to the conditions, which not merely accompanied their eruption and brought about their

alteration, but also whether the latter was in any way due to solfataric action; in other words, whether hot springs and geysers originally existed in the areas where British rhyolites are found.

It cannot at this moment be positively affirmed that we have any evidence of this kind; but a comparison of thin sections of our older rhyolites with those of New Zealand lead to the belief that careful study in this direction will eventually prove that some, at least, of our older rhyolites have been more or less affected by solfataric action. So far I have failed to find any positive evidence upon this point; and I can only mention one or two instances in which sections examined in reflected, as well as in polarized and ordinary transmitted, light have aroused some suspicion.

One case is that of a rock from the northern end of Dufton Pike in Westmoreland. A section of somewhat similar rock has already been described by Mr. A. Harker[1] under the heading 'Rhyolitic Rocks,' in Appendix I to Marr & Nicholson's paper on 'The Cross Fell Inlier.' This section when examined in reflected light, seemed to show a very close resemblance to some siliceous sinters; but this similarity of appearance is hardly to be trusted, since formerly vitreous acid lavas, now devitrified, often present a like aspect, when viewed in reflected light. On submitting part of this specimen to Mr. Philip Holland, he informed me that the total silica in it amounts to only 69 per cent.: a circumstance which strongly supports Mr. Harker's opinion that the rock is a rhyolite.[2]

Another specimen from Carneddau, near Builth, has a brecciated aspect, and so closely resembles H_{42} from Rotorua (p. 504) that a comparison of the sections seemed desirable. Under the microscope, the Carneddau rock is seen to consist of angular fragments of felsite, held together by a brownish cement which still contains much isotropic matter, possibly to be regarded as siliceous sinter somewhat altered. The felsitic fragments show none of the structures characteristic of rhyolites, although such structures may originally have been present.

As to the causes which may convert a glassy into a lithoidal rhyolite, we still seem to lack information; but, as I have suggested in a former paper read before this Society, it is possible that the action of steam may be instrumental in such a change. This, however, is probably only an occasional agent, and the more general cause of such changes must be sought elsewhere.

In microscopic characters the rhyolitic rocks of New Zealand represent, structurally, everything met with in our ancient rhyolites, apart from the alteration which some of the latter have undergone.

The obliteration of original structures by the development of a felsitic condition, as illustrated in the spherulitic rhyolite of Waihi Beach, may account for the comparatively structureless character of some of our old rhyolites, such, for instance, as a considerable

[1] Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 518.

[2] Mr. Harker expresses very guardedly his opinion concerning the groundmass of this rock, which deserves further examination.

proportion of those occurring at Caradoc; and it does not seem unreasonable to suspect that where felsitic lavas are found to be comparatively devoid of fluxion-banding, spherulitic, and other structures so commonly met with in rhyolites, solfataric action may have been instrumental in bringing those rocks to their present condition.

EXPLANATION OF PLATE XXVII.

Fig. 1. Mayor Island [H_{26}].—Obsidian containing gas-inclusions, small crystals of hornblende, and microlites of felspar. ×140. Ordinary transmitted light. (See p. 495.)

2. Waitekauri [H_{27}].—Perlitic obsidian. ×30. Ordinary transmitted light. (See p. 496.)

3. Waihi Beach [H_{31}].—Devitrified spherulitic obsidian, some of the spherulites being partly altered to felsite. ×30. Ordinary transmitted light. (See p. 498.)

4. The same portion of the section as that shown in fig. 3. ×30. Polarized light (crossed nicols).

5. Rotorua [H_{45}].—Spherulitic rhyolite, altered by solfataric action. ×30. Ordinary transmitted light. In this figure only vestiges of the brown spherulites are seen, but, between crossed nicols, the spherulites appear entire, as if no portion of them had been altered. (See p. 506.)

6. Rotorua [H_{42}].—Pumice-tuff, consisting of lapilli of pumice and altered rhyolite? (the latter are not shown in the figure), bordered and cemented by hyalite. ×30. Ordinary transmitted light. (See p. 504.)

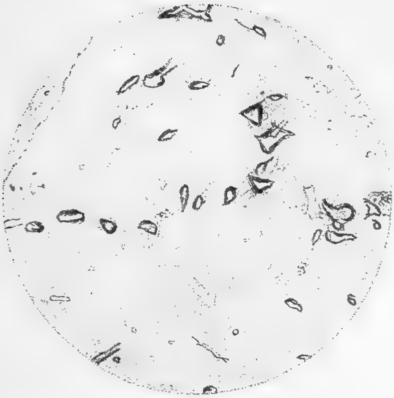
DISCUSSION.

The PRESIDENT said that all the Fellows present would regret extremely the absence of the Author, and still more the cause of that absence. He (the President) had recently examined an extensive series of felsites (rhyolites) and jaspers occurring as pebbles in the Torridonian rocks of Scotland, and had come to the conclusion that the jaspers were in many cases silicified rhyolites. He would now be able to quote the present paper as additional evidence of this conclusion.

Mr. FREDERICK CHAPMAN remarked upon the occurrence of the thread-like bodies in the siliceous rocks of Rotorua, which may possibly be comparable with the filamentous algæ described by Weed from Yellowstone Park and referred by that author to *Leptothrix*, etc. It was also of considerable interest to notice the presence of diatoms in the sinters. From a general examination, the frustules which had their outlines best preserved seemed to belong to the genera *Melosira* and *Epithemia*, and possibly *Orthosira* was present.

Mr. HARKER remarked on the close resemblance between the rhyolites and sinters of New Zealand and those of the Yellowstone Park. The Author's suggestions might also throw light on the origin of certain ancient British rocks, which have probably undergone silicification by solfataric action; but here the results are complicated by the subsequent conversion of the amorphous silica into quartz. Certain rocks in Westmoreland, Caernarvonshire, and Pembrokeshire, consisting essentially of microcrystalline quartz, still preserve the characteristic structures of rhyolitic lavas.

Prof. WATTS also spoke.



1 (×140)

2 (×30)

3 (×30)

4 (×30)

5 (×30)

6 (×30)

Frank Rutley del.
E. Drake lith.

West, Newman imp.

NEW ZEALAND ROCKS.

26. *On* Longmyndian Inliers *at* Old Radnor *and* Huntley (Gloucestershire). By Charles Callaway, M.A., D.Sc., F.G.S. (Read April 25th, 1900.)

[Plate XXVIII—Map.]

Contents.

Introductory.

The rocks of the Longmynd Hills, in Western Shropshire, originally supposed to be Lower Cambrian, are now admitted to be of pre-Cambrian age. In the following pages evidence will be offered which will enable us to extend the distribution of the Longmyndian system to a considerable distance from the typical area.

I. The Longmyndian Inlier at Old Radnor.

The village of Old Radnor is situated on the western slope of an isolated ridge, about $\frac{3}{4}$ mile long, striking north-east and south-west. The mass of the hill is composed of grit, but there are some associated slaty bands, and on both sides of the ridge the Woolhope Limestone is largely exposed. Murchison[1] considered the grits to be May Hill Sandstone, and the Woolhope Limestone was supposed to be in conformable succession with it. He perceived, however, that neither grits nor limestone possessed the normal characters of the groups to which he believed them to belong, and he attributed their peculiarities to the metamorphic action of intrusive igneous masses. On the Geological Survey map, the arenaceous series is described as 'altered sandstone,' and identified as May Hill Sandstone.

Many years ago, I was struck with the close lithological resemblances between the Old Radnor Series and some parts of the typical Longmyndian, and I could not acquiesce in the view that the rocks were 'altered' in the sense of being truly metamorphic; but it was not until the summer of 1897 that I ascertained the existence of a clear break between the Woolhope Limestone and the Old Radnor Series. This discovery enables me to complete my evidence for the Longmyndian age of the latter.

[1] 'Siluria' 4th ed. (1867) p. 108.

1. Unconformity between the Woolhope Limestone and the Old Radnor Series.

On the north-eastern side of Yat Hill, an elevation coalescing with Old Radnor Hill on the south-west, within 90 yards of a slaty outcrop of the Old Radnor Series, the Woolhope Limestone appears at the surface. One bed of it seems to dip in a westerly direction, and as no limestone is seen to the east of it, this is probably the base of the Woolhope Series. It is crowded with rounded and angular fragments of a grit which bears a marked resemblance to the arenaceous part of the Old Radnor Group. The matrix of the fragments is pure limestone, containing abundant specimens of *Favosites* of the *gothlandica*-type. Near at hand on the south is a large quarry, on the southern side of which a similar conglomerate occurs in wall-like masses 6 to 9 feet high, but no clear dip could be determined in it, nor in any part of the limestone of the quarry. The conglomerate is of a most pronounced type, the clear limestone-matrix being packed with fragments of the grit, most of them well-rounded. *Favosites* also occurs in the limestone of the quarry. These facts would seem to suggest a shore, margined by a pebble-beach, forming a foundation for a fringing-reef.

2. Lithological Characters of the Old Radnor Series.

Grit is the prevailing rock, but in a quarry near the church there are some associated slaty bands. They are approximately vertical, with a north-and-south strike, and are somewhat contorted. Fine-grained grit and indurated flinty mudstone occur near the western margin of the Old Radnor mass, 90 yards east of the Yat Hill limestone. The beds dip westward at a moderate angle. These are the only exposures of the Old Radnor Series in which bedding could be detected. I searched Old Radnor Hill from end to end, and could find nothing but grit, without clear stratification. Towards the southern end of the ridge there is a fair proportion of mica, much of which lies in planes dipping at a low angle to the south. Under the microscope, a great part of this mica is seen to be of secondary origin, being in unworn and unbroken crystals, which are moulded to the angles of the other minerals of the grit. This apparent lamination would seem, therefore, to have no connexion with the original sedimentation of the rock.

The obliteration of bedding in the Old Radnor Series is due to crushing, of which very clear proof can be seen in many places. One of the best sections for studying the crush-phenomena is in a large quarry at the north-eastern end of the ridge. The grit is traversed by joints striking in all directions. The joint-surfaces are stained with a black substance, and are often slickensided. The motions which produced the slickensides have not always acted towards the same point of the compass. In some places the rock is crushed into a breccia, with fragments of various sizes, some of them almost microscopic. The rock is brecciated also on the northern slope of the hill, and at many points along the summit-ridge. Sometimes

the breccia may be described as 'nascent,' the rock being traversed by numerous planes of division, the fragments remaining nevertheless in contact, save for the film of infiltrated matter. The crushing forces have evidently acted with varying degrees of intensity; but they have nowhere been severe. They have sufficed to obliterate the bedding of the grit, although they have not produced mylonite, nor have they even flattened out fragments into lenticles.

The following descriptions of thin sections throw light on the constitution of the grit and its degree of alteration. For purposes of comparison, I have included slides from the derived fragments in the Woolhope Limestone:—

[553][1] Old Radnor Hill, northern end.

A grit, composed of angular bits of quartz, some of it showing mosaic structure; and angular bits of felspar (both orthoclase and plagioclase), some of which is partly decomposed into microliths of mica. In less proportion are angular fragments of felsite and andesite. Some scattered particles of epidote and a little mica are also present.

[554] In Woolhope Conglomerate, Yat Hill. For comparison.

A very similar grit, though with less quartz. Felsite and mica more abundant, but less epidote.

[555] Old Radnor Hill, southern end. Selected as micaceous.

Angular quartz, felspar, and felsite as before, the felspar being less abundant than the quartz. Mica, both white and brown, rather conspicuous, much of it roughly orientated in one direction, but some not. It is cut normal to the cleavage, and shows the regular outlines of unbroken mica, except where it is moulded on fragments of quartz and felspar. It would appear to be authigenous, and is associated with cracks in the rock in such a way as to suggest that it is the result of infiltration. It also occurs in cracks in individual fragments of quartz. Judging from this slide, the rock has been but slightly compressed, the mica being the only mineral that shows any approach to parallelism.

[557] Old Radnor Hill, southern summit.

Angular bits of quartz and quartz-mosaic predominating; felspar inconspicuous, some of it partly decomposed; very little felsite or mica; a fair proportion of opacite, apparently resulting from the decomposition of a basic mineral. The slide is traversed by several cracks, on the walls of which is deposited a greenish mineral, and the middle of the cracks is often filled in with opaque matter.

[556] Woolhope Conglomerate, Yat Hill. Derived.

Quartz as in No. 555; felspar in subordinate proportion; felsite fairly abundant; a little mica and mica-schist; a few fragments of a fine-grained grit composed mainly of angular quartz; opacite as in No. 557.

[558] Same locality.

A grit similar to No. 557, but it contains a little chlorite and the opacite is less abundant. The rock is somewhat crushed, and the cracks are filled with calcite.

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[1] The numbers in square brackets are those of the slides in my own collection.

All the foregoing slides are grits, the materials of which are mainly derived from gneissic and igneous rocks. The specimens from the Woolhope Conglomerate differ from the Old Radnor Grit only varietally, and in no greater degree than specimens of the Old Radnor Grit differ one from the other.

3. Pre-Cambrian Age of the Old Radnor Series.

The great dissimilarity between these rocks and the May Hill Sandstone which occurs near Presteign, at a distance of only 3 miles to the north-east, is obvious at a glance; and it was no doubt this difference that led Murchison to infer that the Old Radnor rocks had undergone metamorphism. The chief mass of the May Hill Sandstone, as seen at Nash Scar, is highly quartzose, and sometimes approaches a quartzite in composition and texture. The bedding is quite distinct, and, in some localities nearer Presteign, fossils (such as *Petraia* and *Pentamerus*) are abundant.

Irrespective of this lithological dissimilarity, the (at least) pre-Silurian age of the Old Radnor Series may be inferred from the unconformity indicated by the Woolhope Conglomerate; and the close resemblance between the material of its pebbles and the grit of the Old Radnor mass renders it highly probable that the hill is a fragment of the land which margined the Woolhope sea. The Old Radnor Series must therefore be regarded as pre-Silurian. If this be admitted, its pre-Cambrian age becomes highly probable, and the following considerations will, I think, convert probability into a very near approach to certainty.

(*a*) Geological Position of the Series.

The normal strike of the rocks of the Longmynd is south-south-westerly, and this is steadily maintained from the northern end of Haughmond Hill to the southern extremity of the Longmynd range, a distance of 20 miles. If the Longmynd strata are continued for 19 [1] miles farther along the line of strike, some part of them would coincide with the position of Old Radnor Hill. Furthermore, the eastern boundary of the Longmynd massif is the Church-Stretton Fault. This also is continued south-south-westward, and passes very near the eastern margin of Old Radnor Hill, if not close to it (see map, Pl. XXVIII). The Old Radnor mass is therefore on the western side of the fault, where my theory requires it to be. The Longmynd Series in Shropshire is followed on the west by the Ordovicians of the Stiper Stones area, which reappear on the southern line of strike, 7 or 8 miles west of Old Radnor, at Builth and Llandrindod. It is almost certain, therefore, that the Long-myndian occupies its normal position in the Old Radnor district, and that Old Radnor Hill is a mass of it jutting up amid Silurian strata. It should be remembered also that the May Hill Sandstone of Shropshire is a shore-deposit on the Longmynd Hills, just as is the Woolhope Conglomerate at Old Radnor.

[1] The distance is only 16 miles from the inlier of grit at Hopesay.

(b) Lithological Comparison with other Groups.

The Old Radnor Series is distinctly unlike both the Ordovician and the Cambrian of the Western Midland area. If Ordovician rocks exist in the Radnor district, they must be of the Caradoc type, for the Stiper Stones Series lies far to the west at Builth. But the Caradoc strata of the country east of Church Stretton are mainly quartzose sandstones and soft shales. The Cambrian of Shropshire is made up of quartzite and green arenaceous grits, overlain by the Shineton Shales. These shales occur in their typical facies at Pedwardine, only 9 miles from Old Radnor; and it is fair to assume that, if the Lower Cambrian strata were also continued along the line of strike, they would be similar to the Salopian types. This supposition is rendered almost a certainty by the fact that Cambrian rocks, both Upper and Lower, do appear as far south as the Malvern Hills, and are so similar to the Shropshire subdivisions as to be easily identified by their lithology alone. No one familiar with the Cambrian and Ordovician rocks east of Church Stretton could fail to perceive their great dissimilarity to the felspathic grits and hard slaty beds of Old Radnor Hill.

The lithological resemblances between the Old Radnor Series and the typical Longmyndian are very well marked. In a previous paper,[1] descriptions by Prof. Bonney and myself have been given of the ordinary Longmynd types. They indicate derivation from land composed of gneisses, granites, and rhyolites. A few extracts from these descriptions are here appended:—

> 'Composed of bits of quartz, purple rhyolite, mica-schist, and felspar. Largely derived from granitoid rocks . . . .Composed of quartz, felspar, and a small proportion of volcanic fragments. . . .Bits of quartz and felspar, with mica and a small proportion of felsite.'

The abundance of felspathic material in these slides is characteristic of the typical Longmyndian, and the same feature is well-marked in the Old Radnor Grits. The angularity of the quartz, felspar, and felsite is also common to the grits of both areas. The close lithological resemblances between the two rock-groups, combined with the evidence of geological position and unconformable relation, would seem to place their identity beyond reasonable doubt.

4. The Alleged Metamorphism of the Rocks of the Old Radnor Area.

Both the Old Radnor Series and the Woolhope Limestone are said to have been metamorphosed. Let us take the two cases in order.

(a) The Old Radnor Series.

I have already stated that these rocks do not display material alteration. The felspar, it is true, often contains microliths of mica, but this feature is common in the old gneisses and granites, and there is no evidence that the alteration took place after the conversion of the crystalline material into sediments. Infiltration is

[1] Quart. Journ. Geol. Soc. vol. xlii (1887) p. 482.

not uncommon. The surfaces formed by jointing and crushing are ordinarily stained by a blackish substance, which is opaque in transmitted light, and is possibly iron-oxide. On some of the surfaces is seen a thin coating of a pale-green mineral, which I cannot positively identify. Some of the mica also seems to have been formed in cracks as the result of infiltration (see p. 513). But such cases as these do not prove the action of high temperatures. On the other hand, the fragments in the grit retain their angularity, and the rock as a whole is as unchanged as an ordinary grit from the Longmynd. The infiltration that has taken place is the natural result of a very moderate degree of crushing, which has permitted the access of water. The mineral deposits in the cracks may easily have been derived from the rock itself.

(*b*) The Woolhope Limestone.

I have already referred to the sections at Yat Hill, and remarked that, except at one point, the rock exhibits no clear bedding. A little farther south, near Dolyhir Railway-station, the limestone is well exposed in a large quarry, and here also I could detect no stratification. The rock is massive, traversed by joint-planes hading at high angles, in places crushed into a breccia, and in part crystalline. The fossils that I collected were *Favosites*, of both the *gothlandica* and *fibrosa*-types, a brachiopod (probably *Strophodonta*), traces of small trilobites, and fragments of crinoids. I followed the limestone for ¼ mile or so to the west, and saw several sections, both natural and artificial; but in the course of a somewhat rapid examination I could find no clear stratification. The bedding therefore has been for the most part obliterated, but the presence of fossils shows that the metamorphism is not intense.

According to Murchison,[1] the alteration undergone by the limestone is due to

'the action of heat issuing along a line of fissure, which, emitting the igneous rocks of Stanner, Worsel, and Hanter, fused the strata into huge amorphous masses, and left films of serpentine on the faces and joints of the altered limestone.'

I did not find any of this serpentine; but, if it were present, it would give no support to Murchison's contention.

I may at once remark that the change which the limestone has undergone is not such as we are accustomed to expect at the contact with an intrusive igneous mass. So far as I could ascertain, the rock contains no foreign minerals whatever. What we do find is a certain amount of crushing, and a partial recrystallization. The microscopic examination of three slides reveals the nature of the change produced:—

[559] From the quarry south of Dolyhir Railway-station.

This specimen was selected as containing small rounded patches of a finer grain than the bulk of the rock. These, when enlarged, are seen to be organic bodies of the nature of either *Stromatopora* or *Favosites*, consisting of an

[1] 'Siluria' 4th ed. (1867) pp. 108–109.

aggregation of very minute tubes of equal size, which are apparently, but not very clearly, polygonal. One of these fossils seems almost complete, the margin being nearly entire. The remainder of the margin, as well as a great part of the margin of another specimen, is irregularly serrated, as if corroded. A third specimen in the slide is a fragment. The space between the fossils is occupied by clear calcite: some of this is finely granular; some is in fairly large crystals; and some of it displays a compound polygonal structure, suggesting a *Favosites*. I think, however, that this is only mimicry, and that it is really concretionary, consisting of aggregations of tubular bodies. That it is not organic appears from its relation to the fossils. It is moulded to their corroded edges, and has therefore been formed later.

[560] Same locality.

This specimen exhibits the same general characters, but fragments of unaltered limestone take the place of the fossils. The fragments consist of a somewhat dingy-looking groundmass of very minute particles of calcite. Scattered through this groundmass are small bits of shells and crinoids. The pygidium of a minute trilobite can also be detected. The space between the limestone-fragments is filled with clear calcite, some of it showing the tubular structure.

[561] Quarry on Yat Hill.

The slide is selected as showing a junction between one of the pebbles of grit and the limestone-matrix. Some of the limestone in contact with the grit is unaltered, and is in places stained with brown matter which has found its way along the plane of junction. Some of the matrix is changed to clear calcite, and the tubular structure is also present. The quartz-grains of the grit are very much broken, and the cracks are often filled with calcite, doubtless derived from the matrix.

It would appear from the evidence of these slides that the altered appearance of the rock is due to crushing, followed by the infiltration of carbonated water, which partly dissolved the limestone, and redeposited it as clear calcite, either in well-formed crystals of various sizes, or in aggregations of tubular concretions.

The alterations in both grit and limestone are thus seen to be due to the same causes—crushing and infiltration. Whether the earth-movements producing the crushing are connected with the Church-Stretton system of faults, I am not prepared to say. The southerly dip in some of the micaceous laminæ on Old Radnor Hill would seem to point to a force acting from the south, but it is possible that the crushing-forces have operated in different directions at successive epochs.

It is perhaps hardly necessary to point out that there is no evidence of the intrusion of igneous masses which could have affected the rocks in question. The gabbro, dolerite, felsite, and granitoid rocks of the Hanter and Stanner hills, which are only ½ mile to the east, lie on the south-westerly prolongation of the axis of the Wrekin and Caer Caradoc ranges. Therefore they may be presumably regarded as associated with pre-Cambrian masses hidden by a superficial covering of Silurian sediments, even if they are not all of pre-Cambrian age. They are quite unlike the known post-Silurian eruptive rocks of the region. The dolerite is similar to that intruded in the Uriconian near Church Stretton; the felsite suggests the Uriconian itself; and the granitoid rock is almost certainly of still greater antiquity.

II. The Longmyndian Inlier at Huntley.

It is more than thirty years since Murchison recognized the presence of rocks similar to those of the Longmynd in a quarry west of Huntley. He writes[1] :—

'In approaching the higher ground, the first rock which is observed to jut out from the plain of the New Red Marls, has all the aspect of the Cambrian rocks of the Longmynd. It is a hard, siliceous, close-grained, dark-grey, schistose stone with quartz-veins, and is quarried for the use of the roads.'

This description requires some modification. The rock is 'schistose' only in the sense in which an ordinary grit or shale is 'schistose.' Nor is it predominately 'quartzose.' A typical specimen of the rock, cut for the microscope, is seen to consist mainly of felspar, with quartz in quite subordinate proportion. The former includes both orthoclase and plagioclase. Some of it is in unbroken prisms, the remainder being in irregular angular fragments. The quartz also is in angular bits. The slide contains a fair proportion of a black opaque substance in irregular particles, many of which contain minute elongated prisms of felspar, suggesting a partly decomposed dolerite.

This grit, though it suggested to Murchison, as it did independently to myself long afterwards, a resemblance to the Longmynd Series,[2] does not under the microscope present a very close similarity. Judging from the slide examined, the rock is wanting in the bits of rhyolite which are so characteristic of typical Longmyndian, and it is distinguished by a greater abundance of felspar. Some hand-specimens of the rock are, however, less felspathic. The angularity of the quartz is a feature common to the Huntley rock and to the typical Longmyndian grit. The black grains are not characteristic of the type, but I have seen them in a slide from Haughmond Hill. The shaly beds associated with the grits are also suggestive of the Longmyndian of Shropshire, being more indurated than ordinary shales.

The section exposed in Huntley Quarry presents a thickness of about 80 feet, massive grits predominating over the shaly bands. The beds stand almost vertical, with an easterly dip, but towards the bottom they curve round westward, so that they probably form part of a fold (see the appended section, p. 519). The rocks may be traced across the strike for about 200 yards. They form a small hill projecting like a promontory towards the south, with the Trias faulted against the eastern base, and a hollow dividing the ridge from the May Hill Sandstone on the west.

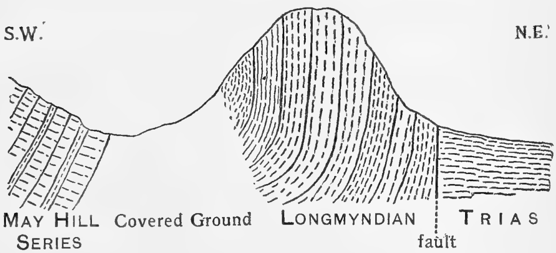
That the Huntley mass is not Silurian appears evident from its dissimilarity to the adjacent May Hill Series. The nearest exposure of the latter occurs in a small quarry in a garden, about 200 yards to the south-west. The rocks are highly quartzose, with

[1] 'Siluria' 4th ed. (1867) p. 99.

[2] [Phillips, Mem. Geol. Surv. vol. ii, pt. i (1848) p. 183, also mentions the older rocks of Huntley Hill when dealing with the Caradoc Sandstone, but he does not remark on their similarity to the Longmyndian.]

partings and thin beds of soft grey shale. The dip is 70° south-westward. The May Hill Sandstone in other parts of the district is also predominantly siliceous, and often contains numerous bits of purple felsite, very similar to typical Uriconian. Many years ago, I found in a quarry (now overgrown) on May Hill some conglomeratic beds in which were pieces of grey shale, undistinguishable from the Shineton Shales of Malvern and Shropshire; and it would seem probable that the shaly partings in the garden-quarry are

Section of Longmyndian and associated rocks at Huntley.



derived from the same source. The May Hill Series is therefore largely derived from land consisting of quartzose rocks, purple rhyolites, and soft shales, an assemblage which offers a strong contrast to the constituents of the Huntley Grit. The materials of the latter include so large a proportion of broken and unbroken felspar-crystals as to indicate an admixture of the ejectamenta of contemporary volcanoes, a common feature in the Shropshire Longmyndian, but one which is not known in our Western Midland Silurian.[1]

The tectonic relations of the Huntley Grits and the May Hill Sandstone could not be ascertained. The Silurian rocks of the district lie in a boat-shaped anticline, whose axis strikes north-westward, but the eastern part is cut off by a north-and-south fault, bringing down the Keuper. The position of the Longmyndian is about on the axis of the anticline, and close to the Keuper. The fault is apparently a continuation of the dislocation which forms the eastern boundary of the Malvern crystallines. This little north-and-south ridge of Longmyndian is approximately on the prolongation of the geographical axis of the Malvern chain, and, like the greater part of that range, has May Hill Sandstone on one side, and faulted Keuper on the other. As these Longmyndian strata strike north and south, it seems probable that they are continued northward, and underlie the Cambrian and newer strata of the Malvern district.

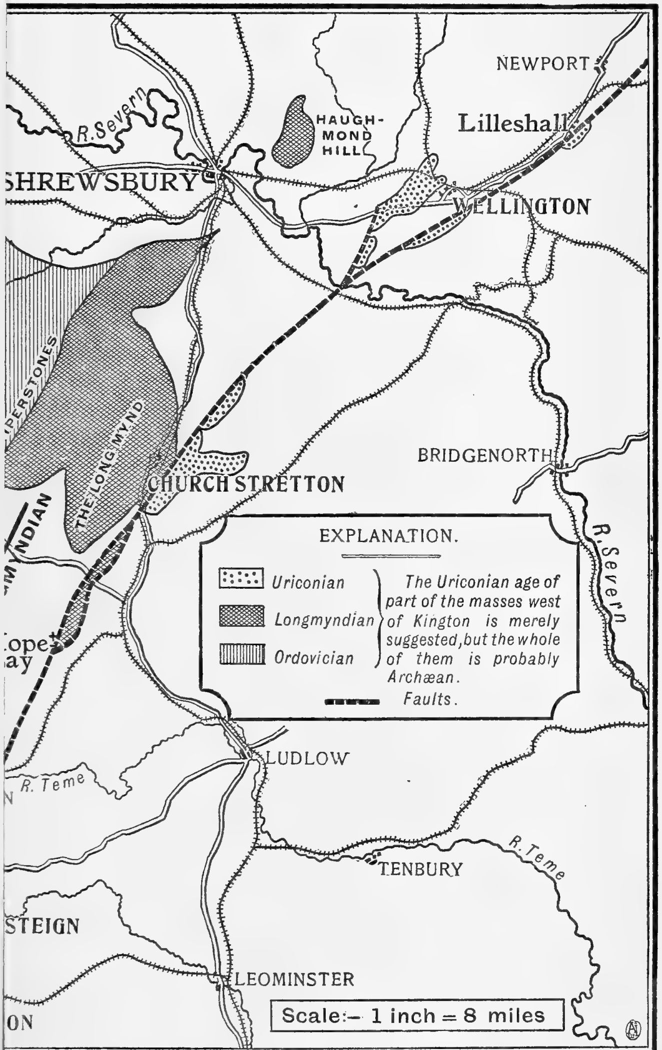
The identification of these outlying masses of Longmyndian rocks enables us to make a considerable extension of the distribution

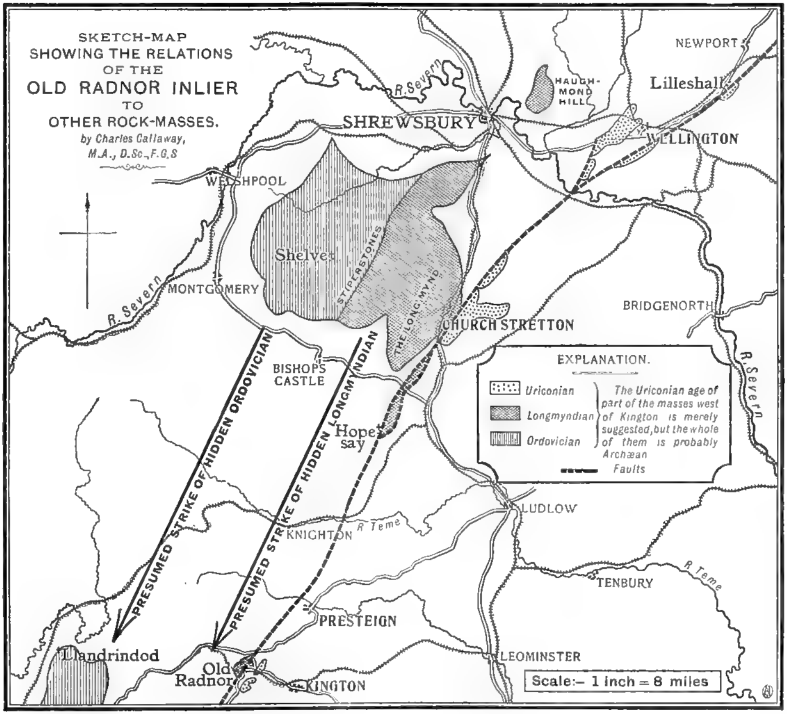
[1] Of course, I do not include the 'Lower Silurian' of Murchison.

of that series. From Haughmond Hill to Old Radnor Hill is well nigh 40 miles; it is nearly the same distance from Old Radnor Hill to Huntley. From Huntley to Haughmond Hill is about 60 miles. These three localities are situated at the angles of an isosceles triangle, whose apex is at Old Radnor, and whose base corresponds for a great part of its course with the Malvern–Abberley axis and its northward continuation. It is highly probable that Longmyndian rocks occupy a considerable portion of this triangular area below the Palæozoic strata, and it cannot be doubted that this ancient series, whose vast thickness is well known, extends far beyond these limits in other directions.

EXPLANATION OF PLATE XXVIII.

Geological sketch-map, showing the relations of the Old Radnor inlier to other ancient rock-masses, on the scale of 8 miles to the inch.


NEWPORT
Lilleshall
R. Severn
HAUGH-
MOND
HILL
SHREWSBURY
WELLINGTON
STIPERSTONES
THE LONG MYND
CHURCH STRETTON
BRIDGENORTH
R. Severn
MYNDIAN
Hope
ay
EXPLANATION.
Uriconian
Longmyndian
Ordovician
The Uriconian age of part of the masses west of Kington is merely suggested, but the whole of them is probably Archæan.
Faults.
LUDLOW
R. Teme
TENBURY
R. Teme
STEIGN
LEOMINSTER
ON
Scale:– 1 inch = 8 miles


SKETCH-MAP
SHOWING THE RELATIONS
OF THE
OLD RADNOR INLIER
TO
OTHER ROCK-MASSES.
by Charles Callaway,
M.A., D.Sc., F.G.S
NEWPORT
Lilleshall
HAUGH-
MOND
HILL
R. Severn
SHREWSBURY
WELLINGTON
WELSHPOOL
Shelve
STIPERSTONES
THE LONG MYND
MONTGOMERY
R. Severn
BRIDGENORTH
CHURCH STRETTON
BISHOPS
CASTLE
PRESUMED STRIKE OF HIDDEN ORDOVICIAN
PRESUMED STRIKE OF HIDDEN LONGMYNDIAN
Hope-
say
EXPLANATION.
Uriconian
Longmyndian
Ordovician
The Uriconian age of part of the masses west of Kington is merely suggested, but the whole of them is probably Archæan
Faults
R. Severn
LUDLOW
KNIGHTON
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PRESTEIGN
Llandrindod
LEOMINSTER
Old
Radnor
KINGTON
Scale:— 1 inch = 8 miles

27. *On the* DISCOVERY *and* OCCURRENCE *of* MINERALS CONTAINING RARE ELEMENTS. By Baron ADOLF ERIK NORDENSKIÖLD, F.M.G.S. (Read April 4th, 1900.)

THE remarkable discoveries of recent years with regard to the composition of the air, and the discovery of several new gaseous elements, have again unexpectedly directed general attention to those Scandinavian minerals which contain rare earths and acids. It will, therefore, be the more proper to give here a brief sketch of the discovery of these minerals, as most of them were not only first found in Sweden, Norway, Finland, or Greenland, but also first described by Swedish observers in the Transactions of the Royal Swedish Academy of Sciences. In doing this I shall have an opportunity of correcting some mistakes and inadvertencies of foreign investigators as to the history of these discoveries, and of showing the groundlessness of certain geological or cosmological speculations which have been induced by the unexpected observation that the new gases, when occurring in the crust of our planet, seem to be particularly associated with minerals containing rare earths.

A mineral containing earths of this kind is mentioned for the first time in mineralogical literature in a paper by Axel Fr. Cronstedt, entitled 'Experiments & Trials made on Three Iron-ores,' and printed in the K. Svenska Vetenskapsakademiens Handlingar in 1751. One of these supposed iron-ores consisted of a substance in which there is no iron at all, namely, the greyish-white heavy mineral from Bispberg in Dalecarlia which is now called scheelite, and from which, thirty years later, Scheele first separated the oxide of the important element wolfram. This element is still called tungstène by French chemists, from the name Bispbergs tungsten (heavy stone) given by Swedish miners to the mineral in which the oxide was discovered. Another of these 'iron-ores,' Bastnäs tungsten, which, according to the quite correct observation of Cronstedt, 'contained iron, together with an earth which fuses very slowly to a slag,' is the mineral from which, in the beginning of the nineteenth century, Berzelius and Hisinger, and, independently of them, Klaproth, obtained the oxide or earth of a new substance, cerium. In the years 1839–1842, however, this earth was decomposed by Mosander into the oxides of cerium, lanthanum, and didymium; and in 1885 the Austrian chemist, Auer von Welsbach, succeeded in isolating from the didymium-oxide of Mosander a fourth element, to which the name praseodidymium was given.

Thus no less than four out of the seventy or so elements of which the crust of the earth and its gaseous envelope are formed have been discovered in Bastnäs tungsten or, as the mineral is now called, cerite. Since then these substances—cerium, lanthanum, didymium, and praseodidymium—have also been met with in a number of other minerals chiefly occurring in northern countries. They

have obtained a great systematic importance for chemical science, and also have been practically utilized, as for example (together with thoria) in the solutions with which mantles are impregnated for the production of the Welsbach incandescent light.

This incandescent light had been observed already by Cronstedt. In his above-mentioned paper he writes, concerning the Bastnäs tungsten, as follows :—'When it is fused with charcoal-powder zinc is seen to burn with its usual flame, but in the brass test the copper does not increase in weight.' In order to understand the meaning of this, one must remember that at that time the dazzling white light which zinc emits when burning was regarded as characteristic for zinc-ores, as also the reaction that takes place when copper fused in a crucible with a substance containing zinc is turned into brass and augments in weight. Hence the remark of Cronstedt, which shows that the beautiful incandescent light of the rare earths had been noted already in the middle of the eighteenth century by our observant metallurgists. They had mistaken this light for that which radiates from glowing *lana philosophica*, and played so mysterious a part in the fancies of the alchemists.

Among the minerals remarkable in the history of the discovery of the rare earths or acids, the one met with next after Bastnäs tungsten is a black, obsidian-like substance from the felspar-quarry at Ytterby, near Stockholm. This mineral is mentioned for the first time under the name of black zeolite in a letter from Bengt Reinhold Geijer, published in Crell's 'Chemische Annalen' for the year 1788. Six years later John Gadolin, then lecturer on chemistry at the University of Åbo, published in the Transactions of the Royal Swedish Academy of Sciences a chemical analysis of this mineral, by which he proved that it contained a new earth, different from lime, magnesia, and alumina, from the baryta of Scheele and the strontia of Klaproth, and characterized by its precipitation from acid solutions by oxalic acid.

Later, in 1797, Vauquelin discovered glucina, in emerald and beryl. The discovery of these new earths was then as unexpected and as important to chemical science as T. A. Arfvedsson's discovery of the alkali, lithia, in 1818; Berzelius's discovery of the element selenium in 1818; and Rayleigh & Ramsay's discovery of new elements in the atmosphere of the earth in our own days. A closer examination of the 'black mineral from Ytterby and the curious earth found therein' by Anders Gustaf Ekeberg, Professor of Chemistry at Upsala, was published in the Transactions of the Royal Swedish Academy of Sciences in 1797. The new substance was there called ytterjord (=yttria), and the obsidian-like mineral from which it had been obtained, yttersten, a name afterwards changed to gadolinite.

A number of minerals are now known containing elements of the cerium group, but the mineral (cerite) in which cerium was first discovered has so far been found only at the mines of Bastnäs. The

felspar-quarry at Ytterby was likewise the only locality for gadolinite and yttrotantalite until 1814, when these minerals were discovered by Berzelius and Gahn in the pegmatite-veins of the neighbourhood of Falun. Some thirty years later gadolinite was also met with by Keilhau in an analogous formation at Hitterö in Norway. Since then several new localities for gadolinite have been discovered in Sweden and Norway, as well as in North America. Moreover, several other minerals have been found, containing gadolinite-earths as essential ingredients: all of them are, however, of rare occurrence. Most of them are found only in pegmatite-veins in Scandinavia, chiefly within a broad, geographically well-defined zone extending on both sides of the 60th parallel of latitude, from the northern shore of Lake Ladoga across Southern Finland, Central Sweden, Southern Norway, and as far as the south-western coast of Greenland. In the course of the last few years some localities closely resembling those of Scandinavia have been recorded in the United States. Sometimes also minerals containing yttria have been found, with monazite, in considerable quantities in river-sands. Outside of Scandinavia, however, these minerals are of extremely rare occurrence *in situ*. To procure the raw material necessary for obtaining only a few grammes of yttria from the mines or quarries on the continent of Europe or in Great Britain would be an all but impossible task.

Among the minerals containing gadolinite-earths in any quantity worth mentioning, it may suffice here to add the following: phosphate of yttria or xenotime and yttrocerite, discovered by Berzelius; euxenite discovered by Th. Scheerer; yttrotantalite and fergusonite, discovered by Ekeberg and Giesecke. A detailed account of these discoveries and of their great importance for science cannot, however, be given here. I shall only, as an instance of the interest which may attach to even apparently inconsiderable finds in this respect, mention two finds of yttria-minerals made of late years.

One of the latest discovered and perhaps one of the richest localities for such minerals is a pegmatite-vein at Österby in Dalecarlia. Fluocerite, otherwise very rare, occurs here rather abundantly, together with a compact or indistinctly crystalline mixture of orthite, gadolinite, and other minerals long known as containing rare earths. Recently Herr Charles Benedicks, when examining several specimens of fluocerite from Österby, found another new yttrium-silicate, differing from gadolinite in its light-yellow colour, its crystalline structure, and its chemical composition. It occurs very sparingly and would be little deserving of attention, did it not contain, besides the usual constituents of yttrium-silicates, 1·5 per cent. of nitrogen and helium. This comparatively large percentage of inert gases which the Österby mineral has in common with many, perhaps most of the minerals containing rare earths, invests it with an importance greater than it could claim on account of its composition or mode of occurrence. The presence of helium has been ascertained

by means of spectrum analysis by Thalén, after whom the mineral has been named thalenite.

The other mineral, kainosite, was discovered by me in 1886 on examining a large collection of fine specimens of gadolinite from Hitterö. It is a silicate-carbonate of yttrium and calcium; consequently, as the name also indicates, of a rather uncommon composition. What induces me to mention it in this place is the circumstance that the same mineral has since (in 1896) been found by Dr. G. Flink and Prof. H. Sjögren in the form of small, though well-developed crystals in the flucan clays and on the walls of the fissures and drusy cavities at the Nordmarken Mines. I had previously observed that the clay, which partly fills the drusy cavities and fissures there, contains small detached crystals of a great number of recently-formed minerals, different in different fissures. Thus, for instance, fine, sharply defined, quite uncorroded crystals of augite, garnet, epidote, titanite, calcite, and pholidolite may be obtained by washing from the clay of one fissure; crystals of apophyllite and amphibole from that of another; crystals of pyrosmaltite, amphibole, and magnetite from a third; and so on.

All these minerals, though occurring in our oldest rocks, are recent formations—geologically speaking, children of the latest birth. Their mode of occurrence, in veins which are in course of formation in our older rocks, suggest speculations of wide scope with regard to the origin of a certain kind of pegmatite-veins. In the vicinity of Arendal I have seen a fissure like those just mentioned filled with clay enclosing large crystals of quartz, mica, and felspar, evidently of recent formation, running alongside a pegmatite-vein rich in minerals containing rare earths. Large lenticular masses of a cerium-mineral, allanite, occur along the lode at the iron-mines of Gyttorp, near Nora. These mines are, next to the Bastnäs Mines, the richest in cerium-ore hitherto known. On the other hand, no real yttria-minerals, except the kainosite just mentioned, have been met with in the fissures alongside our iron-ore lodes. The occurrence of the unimportant yttria-mineral in the fissure-clay at Nordmarken, and the occurrence of allanite at Gyttorp, indicate that the mode of formation of newly originated fissure-minerals in our mines and that of the pegmatite-veins in our older rocks do not differ so much as is generally supposed.

During the century that has elapsed since the discovery of yttria, a number of new elements have been separated out of this earth, which were at first presumed to constitute the oxide of a single element. Thus, in 1842, erbium and terbium were obtained by Mosander; then, chiefly by Marignac, Cleve, and Nilsson, with the aid of spectrum-analysis, thulium, holmium, scandium, ytterbium, demonium, etc.: in a word, a comparatively large number of the seventy or more elementary bodies of which all known matter consists. However, none of these new substances have as yet been utilized in the arts, and many persons will, therefore, probably consider the results

gained as far from proportionate to the work devoted for many years, nay for generations, by numerous investigators to the separation of these earths. We are evidently confronted here by one of the most difficult problems of experimental chemistry. Probably, however, we have here a clue to important information concerning one of the fundamental tenets of modern chemistry: the doctrine that all matter is composed of a certain number of simple and intransmutable substances,—a doctrine not easily acceptable by the philosopher, yet, as it would seem, more firmly founded on innumerable experiments than any other scientific hypothesis.

Closely allied in several respects to the earths contained in gadolinite is the oxide of another element, discovered by Berzelius in 1829 and described by him in the Transactions of the Royal Swedish Academy of Sciences under the name of thorium. He found it in a black gadolinite-like mineral sent to him by the Rev. M. Thrane Esmark. The mineral occurred very sparingly in the zircon-syenite district on Langesund Fjord in Norway: this is one of the richest-known localities in distinct mineral-species. Its only rivals in this respect are the iron- and manganese-mines in the ore-field of Philipstad, the volcanic region of Vesuvius, and the neighbourhood of Kangerdluarsuk Fjord in Greenland. The Norwegian locality, often, though less correctly, called Brevig in mineralogical literature, was discovered at the beginning of the nineteenth century by J. Esmark. Since that time it has been visited by numerous Norwegian and foreign mineralogists; and a few years ago Prof. W. C. Brögger published an excellent mineralogical description of the locality.

Thoria is distinguished by its weight, which approaches that of lead, and by several chemically remarkable reactions, which were admirably made out by Berzelius, though he had only a few grammes of the new mineral at his disposal. For a long time thorium remained one of the rarest of elements, though it was soon met with as a subordinate constituent in a number of other minerals. Thus in 1839 Karsten, Professor at the Mining Academy of Freiberg, found that thorium enters into the composition of a mineral discovered a few years before in the Ilmen Mountains (Ural), to which the name monazite, from *μονάζειν*, to be alone or rare, had been given. Karsten's statement was doubted by many chemists, but confirmed by Berzelius. Furthermore, thorium was found, though only in small percentages, in pyrochlore from Brevig by Wöhler; in euxenite from Arendal by Mosander and Chydenius; in gadolinite, mixed with orthite, from Ytterby by A. J. Wimmerstedt: and in a brown, altered variety of orthite (called vasite) from Rönnsholmen near Vaxholm by Fr. Bahr.

As recently, however, as about 1870 the thorite from Brevig (or the variety of it which was called orangite) was the only mineral that yielded the raw material necessary for obtaining even a few grammes of thoria. To procure a few hundred grammes of this earth would at that time have been considered by every chemist as quite impos-

sible. But in 1876 I found that thorite occurred more abundantly than at Brevig in some pegmatite-veins in the neighbourhood of Arendal; and two years previously, on examining the minerals associated with the gold which is washed in Finnish Lapland, I had ascertained that monazite occurs there in comparatively large quantity. More recently, thorite has also been met with in fair abundance at several new localities in Southern Norway.

Thoria, mixed with slight quantities of other rare earths, is now largely and profitably utilized for the production of the Welsbach incandescent light. At present, probably a hundred thousand Welsbach lamps, or, as they might be called, thoria-lamps, are in use in Sweden alone; and for these lamps about 100 kilogrammes of thoria-salts are required every year. As a consequence of this 'thoria-ores' are in great demand; they were for some time the object of a lucrative export from the felspar-quarries of Southern Norway. This export, however, ceased after it was found that the sand of several river-beds in the Brazils and South Carolina, like the auriferous sand at Ivalo in Finland, contains so large a percentage of monazite that it will pay to ship this sand to Europe, where the thoria contained in the monazite is extracted.

In 1785 Cavendish, when analysing air, first by the admixture of oxygen and the oxidation of the nitrogen with the aid of the electric spark, and then causing the oxygen to be absorbed by appropriate means, found that a small gas-bubble, which could not be destroyed in this way, always remained in the eudiometric tube. As we now know, this gaseous residue consisted of the substance, discovered more than a century later by Rayleigh and Ramsay as a hitherto unknown constituent of the air, and named argon.

In argon small percentages of two more gaseous elements, crypton and neon, have since been discovered, to which possibly a third, metargon, will have to be added. Thus, the close and careful examination of the infinitesimally small gaseous residue in Cavendish's eudiometer has proved wonderfully rich in scientific results. Berzelius, when analysing thorite (1829), had also observed that the mineral, when heated, yielded, besides water and a little carbon-dioxide, nearly ·5 per cent. of an inert gas. A closer examination of this gas, however, could not be made by him, owing to the scanty supply of material available for analysis. This gaseous residue probably consisted of a mixture of nitrogen and helium, that is, of nitrogen and the element which, discovered several years ago in the envelope of the sun by means of spectrum-analysis, was named helium by Frankland and Lockyer, and has since been discovered by Ramsay in several terrestrial minerals, chiefly in such as contain rare earths.

It was not, however, from thorite that helium was first isolated, but from another mineral containing thoria. This mineral was discovered by me in 1877 among specimens from the quarries near Arendal, and was named cleveite. The same mineral was found a few years later by Prof. Brögger among samples from the felspar-

quarries near Moss, and was described by Blomstrand under the name of bröggerite. We have here a remarkable mineral, the commonest (not thoria-bearing) variety of which already many hundred years ago attracted the attention of the miners and metallurgists of Saxony, and proved the source of much trouble to them. It was a black mineral, heavier than any other in the earth's crust except the native metals. From its weight the miners concluded that it must contain a metal, perhaps gold, the heaviest that they knew. All their attempts, however, to obtain the metal from this ore, either by fire or by corrosive liquids, proved total failures. The old miners held it to be a spell-bound ore, changed into worthless rock by malevolent gnomes, and they contemptuously gave it the name of pecherz. Only a century ago Klaproth succeeded in isolating from this enchanted ore a new element, which he called uranium after the planet Uranus, discovered a short time before by Herschel. The name reminds us also of the belief, prevailing up till the middle of the eighteenth century, that the number of planets in our solar system corresponds with the number of metals in the earth's crust.

A remarkable gap in the chemical system was thus filled, and the use of uranium-preparations in porcelain- and glass-manufacture, in photography, and as chemical reagents, has gradually become so widely extended that £50,000 worth or more of uranium-minerals is consumed every year. The only localities from which uranium-ore has hitherto been obtained in fairly large quantity are the Cornish tin-mines and those in the border-districts of Saxony and Bohemia. Uranium-minerals are obtained in smaller quantity from several other localities. Sweden, however, is the fortunate possessor of the largest, though as yet unworked, deposit of uranium-ore in existence. A few years ago I found that the ashes of a bituminous coal-mineral, called kolm, which is abundantly associated with the Cambrian alum-slate of Vestrogothia and Nerike, contain nearly 3 per cent. of uranium-oxide. Cleveite is closely allied to the Bohemian or Cornish uranpecherz, but differs from the last-named by its considerable percentage of thoria—and it is especially noteworthy that this percentage of thoria seems invariably to concur with a tolerably large percentage of nitrogen (first discovered in this mineral by Hillebrand), and of helium (first separated from cleveite in 1895 by Ramsay).

The statement that uranpecherz was the first mineral in which nitrogen was shown to be present, is, however, not quite accurate. As far back as 1805 Valentine Rose showed that apophyllite, a finely crystalline hydrous fluosilicate, yielded ammonia when heated, and consequently contained nitrogen. Later on, Berzelius showed that a great many hydrous silicates, when heated before the blowpipe, yielded water containing ammonia; and for thorite he directly stated the percentage of the gases which the mineral yields when heated, after the absorption of the vaporized water and of free carbon-dioxide. Moreover, in 1827 Jean-Baptiste Chevallier found that natural ferric oxide mostly contained ammonia,

an observation subsequently confirmed by Berzelius, who, to his astonishment, found this to be the case even with the most compact magnetite from Dannemora.

As I have already stated, cleveite was the first terrestrial mineral in which helium was shown to be present. The occurrence of this gas has since been proved in a number of other minerals containing rare earths: that wherein it has been found in the greatest quantity being fergusonite, which in all other respects has a composition quite different from the composition of cleveite, since in fergusonite the rare earths are combined with tantalic and niobic acids. The history of the discovery of this mineral and of the rare metallic acids which it contains also presents interesting and instructive features which cannot be passed over even in so brief a sketch as the present.

Tantalic acid was discovered in 1802 by Anders Gustaf Ekeberg, Professor of Chemistry at the University of Upsala, in a black mineral, resembling iron-ore, from Skagböle in the parish of Kimitto (Finland). This mineral had attracted attention by its high specific gravity, which is 7 or 8 times that of water. It had been already casually mentioned in a dissertation 'On the Nature of Tin & its Ores,' published in 1772 at the University of Åbo by August Nordenskiöld. On closer examination Ekeberg discovered that the supposed tin-ore contained the acid of a new element, tantalum, and the mineral was named tantalite. It has since then been found at other localities, but always in small quantity: as, for example, by Berzelius in the neighbourhood of Falun, and by Nils Nordenskiöld in the parish of Tammela (Finland). In the same year as that in which Ekeberg published his treatise on tantalic acid, Charles Hatchett described in the Philosophical Transactions of the Royal Society an element closely related to tantalum, which he called columbium, a name that has since been supplanted by niobium. Ekeberg subsequently found that tantalic acid also enters into the composition of a mineral from Ytterby, which was named yttrotantalite.

A new locality for these minerals, or others allied to them, was discovered in the first decade of the nineteenth century by Karl Ludwig Giesecke. This remarkable man, who began life as an actor and playwright, devoted himself zealously to the study of mineralogy, obtained or assumed the title of a Prussian Bergrath, went to Copenhagen, and was entrusted by the great Færöe and Greenland Companies with the mineralogical exploration of those outlying dominions of the Danish crown. He dwelt for a long time in Greenland, travelled by boat with the natives along its western coast, and long after his departure his memory was cherished by the officials of the Company as well as by the childlike and simple-minded natives. After his return, he was invited to come to Scotland to give an account of his discoveries and the localities of the minerals which he had collected in Greenland and sent home. During the Napoleonic wars these collections had been confiscated by British men-of-war and sold by auction. In this way they had

come into the possession of Thomas Allan, the Scottish mineralogist, after whom the cerium-bearing mineral allanite (which also occurs abundantly in Sweden and Norway) has been named. From Scotland Giesecke repaired to Dublin, where he became Professor of Mineralogy to the Royal Dublin Society; he was subsequently knighted, and a medal was struck in his memory.

Giesecke's long stay and extensive travels with the Eskimaux in Greenland produced important results from a mineralogical point of view; he discovered a great number of interesting localities rich in minerals new to science.

During the latter half of the nineteenth century several new, unexpectedly rich finds of minerals have also been made in these distant regions: thus, in 1853 and 1854 by Director H. Rink; in 1870 by the Swedish Expedition to Greenland; in 1876 by Prof. K. J. V. Steenstrup as a member of a Danish expedition to Greenland; and in 1897 by Dr. G. Flink.

One of the minerals collected by Giesecke was described under the name of fergusonite in the Transactions of the Royal Society of Edinburgh for 1826 by Haidinger. The first analysis of the mineral was made two years later in the laboratory of Berzelius by Victor Hartvall, Professor of Chemistry at the University of Helsingfors. Fergusonite attracted the attention of specialists on account of its composition (it consists of gadolinite-earths combined with tantalic and niobic acids) and certain peculiarities in its crystalline form. But it remained an extremely rare mineral, represented even in rich collections only by small fragments of crystals, until I found, on examining the different 'varieties' of yttrotantalite from Ytterby, that one of them consisted of true fergusonite, with the same composition and unusual crystalline form as the mineral from Greenland. Moreover fergusonite had already been found in 1855 in Norway, but the Norwegian fergusonite had been described by David Forbes and Tellef Dahll as new minerals under the names of tyrite and bragite. During the later years of the nineteenth century the same mineral has also been found at several localities in the United States, and has been obtained in fairly large quantity from Ytterby, as well as from various new Norwegian localities.

Fergusonite has lately become of special interest from a chemical point of view, through the discovery that it contains a considerable amount of inert gases. When heated to 500° the mineral suddenly begins to ignite, and yields, according to Prof. W. Ramsay, 1·43 cubic centimetres of inert gases per gramme of the mineral. From this feebly ignited mineral 1·215 cubic centimetres of gas could further be driven off by fusion with potassium-bisulphate. About two-thirds of this gas, corresponding, at normal temperature and normal pressure, to about 10 times the volume of the mineral, consists of helium. Thus fergusonite affords one of the richest materials hitherto known for obtaining this mysterious gas (or mixture of gases) which on our planet seems to be almost exclusively confined to minerals containing rare earths; and just as the earth

that enters into these minerals always consists of a mixture of several oxides, so too the inert gas which the mineral yields seems to contain not one but several closely allied gases. The group of earths as well as the group of gases of which we are here speaking might, therefore, be compared with certain genera among organic beings whose species, not having yet been fully differentiated, present to the descriptive zoologist or botanist difficulties analogous to those with which the chemist meets in trying to separate the rare earths and the rare gases.

As fergusonite is a compact substance free from such pores or minute cavities as occur so abundantly in many minerals, the helium in it must, as Prof. Ramsay observes, be in some way chemically combined. As yet, however, we have no more tangible idea of the nature of that combination than we have of the mysterious connexion that seems to exist between the rare gases and the rare earths. Some philosophers have tried to give an explanation of this, by assuming that the pegmatite has broken forth as a glowing melted mass or a heated magma from the interior of the earth; and that helium is exclusively bound to the minerals of the pegmatite, on the ground that this gas, which (owing to its slight molecular weight) could not in its free state remain in our atmosphere, has been imprisoned in the interior of the globe on account of the high pressure there prevalent. This explanation is, however, quite untenable, being based on an erroneous assumption concerning the nature of the pegmatite-veins that contain the rare minerals. These viens thin out at an inconsiderable depth below the earth's surface; they have no connexion with a solidified granitic magma in the interior of the earth; and the minerals that contain the rare earths are mainly confined to the flucans alongside the pegmatite-veins, which are, like calcite-veins in the older rocks, geologically speaking, children of the latest birth. In many places they even appear to be still in course of formation.

The presence, therefore, of helium and rare earths in the minerals found in these veins is still, like many other facts connected with the mode of occurrence and the chemical constitution of the recently discovered gases and the rare earths, a mystery to the student free from an uncritical predilection for antiquated theories and hypotheses.

Discussion.

Prof. Miers remarked on the isolated occurrence of the rare elements in certain patches of the earth's surface, and deplored the ignorance which at present prevails concerning their distribution in Cornwall, where rhabdophane, churchite, and monazite have been discovered: monazite he had himself found in the slate at Tintagel. The interesting historical survey given in the present paper directed attention to the importance of the mineralogical distribution of these rare elements.

The President also spoke.

28. *On* Kentallenite *and its* Relations *to* other Igneous Rocks *in* Argyllshire. By J. B. Hill, Esq., R.N., and H. Kynaston, Esq., B.A., F.G.S. (Read May 23rd, 1900.)

[Communicated by permission of the Director-General of H.M. Geological Survey.]

[Plates XXIX–XXXI.]

Contents.

I. Introductory.

In Mr. Teall's well-known work on 'British Petrography' a remarkable rock from the Kentallen quarries, near Ballachulish in Argyllshire, was figured and briefly described,[1] but it was not until the rock had been mapped by Mr. J. Grant-Wilson in 1896 that its peculiar characters were recognized and more fully described by Mr. Teall in the Annual Report of the Geological Survey under the term olivine-monzonite.[2] This term was assigned to the rock on account of the resemblance which it showed to the monzonite-group of Prof. Brögger.[3] Mr. Teall pointed out, however, that there was at the same time a considerable difference, consisting mainly in the relative proportion of magnesia, between the Highland rock and the olivine-monzonite rock of Brögger. Since that time similar and closely-allied rocks from other localities have been investigated by us; and it is our object in the present paper to endeavour to point out the relationships of this unique petrological type to the granites and other intrusive rocks of Argyllshire, and so to remove it from a hitherto somewhat isolated position. Moreover, an examination of several varieties of the normal type has led us to reconsider the advisability of retaining Prof. Brögger's term for a group of rocks which evidently show in certain respects a marked divergence from the original type.

The term monzonite originates from Prof. A. de Lapparent (1864), who applied it to the well-known augite-syenite of Monzoni,

[1] J. J. H. Teall, 'Brit. Petrogr.' 1888, pl. xvi, fig. 1.

[2] Ann. Rep. Geol. Surv. 1896 [1897] pp. 22 & 23.

[3] 'Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol' no. ii of 'Die Eruptivgesteine des Kristianiagebietes' Vidensk. Skrift. No. 7, Kristiania, 1895.

in the Tyrol. Since then the term has been employed by different authors in slightly varying senses, but in the main as applying to rocks of the Monzoni facies. More recently Prof. Brögger has made a study of these rocks, and has used the term in a far more extended sense. He includes under monzonite a large variety of rocks, with a silica-percentage ranging from 71·42 down to 49·40, in which plagioclase and orthoclase occur in approximately equal proportions. Typical monzonites, according to him, are essentially orthoclase-plagioclase rocks, forming an intermediate group (übergangsgruppe) between syenites and granites on the one hand, and diorites and gabbros on the other. It is true that the typical rock of Kentallen might fairly be described as a slightly more basic variety of the Monzoni rock, with the addition of olivine as one of the principal constituents. But in consequence of Brögger's paper, the term has come to be associated with the presence of an approximately equal amount of the two felspars—a feature which cannot be said to be an essential characteristic of our group, while in other respects it is clearly defined. In short, we have in Argyllshire a distinct rock-type, possessing at the same time affinities with the extreme basic variety (olivine-monzonite) of Brögger's group, and showing constant features in widely-separated intrusions. Taking these and other facts into consideration, it has seemed to us advisable to propose a new name for these peculiar Argyllshire rocks. It would, moreover, be unsuitable to employ the term monzonite in the present case in its former signification of augite-syenite, on account of the differences in mineralogical and chemical composition between our type-rock and rocks of the syenite-family. Taking, therefore, the Kentallen rock as our type, we propose that the term kentallenite should be substituted for olivine-monzonite. Kentallenite may be briefly defined as a coarse or medium-grained holocrystalline rock, consisting of olivine and augite, with orthoclase, plagioclase, and biotite in varying proportions. It is allied not only to the olivine-monzonites (Brögger) of Scandinavia, but also to a peculiar basic rock, associated with syenites in Montana, termed shonkinite by Messrs. W. H. Weed & L. V. Pirsson. These relations will be more fully pointed out in the sequel.

II. Distribution, Mode of Occurrence, and Description of the Rocks.

Although the peculiar characters of the kentallenites were not fully recognized at the time, it should be pointed out that they were first mapped by one of us in the Ben Bhuidhe area, about 8 miles north-east of Inveraray, in 1892. In 1896 the rock was again found near Loch Avich, about 9 miles south-west of Kilchrenan, and was briefly described in the Annual Report of the Geological Survey for that year[1]; while at the same time appeared Mr. Teall's description, already referred to, of the Kentallen rock. Again, during last

[1] Ann. Rep. Geol. Surv. 1896 [1897] pp. 23 & 24.

summer (1899) another mass has been mapped in Glen Orchy, and Mr. R. G. Symes has reported yet another occurrence of the rock near Loch Avich. Thus we have, besides the exposure near Ballachulish, one exposure in the Ben Cruachan area, namely, in Glen Orchy; two exposures in the Loch Avich area; and two exposures in the neighbourhood of Ben Bhuidhe. It is believed that these six exposures constitute the only known occurrences of this rock in Britain.[1] It will be seen, therefore, that the area over which the rock is distributed is a considerable one, extending from Ballachulish on the north-west to Ben Bhuidhe on the south-east; and from the upper part of Glen Orchy on the north-east to the Loch Avich area on the south-west.

In the course of our work on the Geological Survey, we were enabled to revisit the Ben Bhuidhe district in June 1899, and to collect the additional facts with regard to these peculiar intrusions, and more especially the evidences of their relationships with the diorites and granites of the district, which are presented in the following pages.

Kentallenite occurs as intrusive masses, varying in size, in the younger Highland schists of Argyllshire. Occasionally these masses, as in the neighbourhood of Loch Avich, have a dyke-like behaviour. More usually, however, the intrusion takes the form of a lenticular or roughly oval-shaped mass. The larger of the two Ben-Bhuidhe intrusions forms a broad oval mass, exposed for a distance of $\frac{1}{2}$ mile in Brannie Burn (see Map, p. 542). In Glen Orchy again is a more elongated lenticular intrusion, well exposed in the burn flowing into the river immediately above the Falls of Orchy. In each locality, the rock has a similar aspect, and shows a characteristic mode of weathering: it is black when freshly fractured, and weathers to a rusty brown. Huge, rugged, and disintegrated blocks mark the outcrop of the intrusion, and show a curious pitting of their surface from the action of the weather. A weathered block or boulder may frequently be seen to be covered with numerous cup-shaped depressions (up to 9 or 10 inches in diameter), often resembling the potholes in the bed of a stream. These will hold rain-water and growths of moss and lichen, and so assist the action which doubtless such growths largely contributed in starting.

At Kentallen the rock has been quarried for many years, and is locally known as 'black granite.' A hand-specimen is frequently coarse in texture, and biotite, augite, and olivine can be easily recognized with the naked eye. The brown mica occurs in large

[1] Since the above was written, our colleague Mr. J. S. Grant-Wilson has informed us of two additional occurrences of kentallenite in the Ballachulish area: one in Glen Duror, about $1\frac{1}{2}$ miles south of Kentallen; and the other $\frac{1}{2}$ mile south-west of Dalnatrat, and about 4 miles south-west of Kentallen. The Glen-Duror intrusion is a boss-like mass, but is too decomposed for satisfactory description. The other occurrence is in the form of a dyke, and the rock is exactly similar to that of Kentallen.

plates in the coarser varieties, and shows a characteristic lustre-mottling.

As regards the microscopic characters of the type-rock, we cannot do better than quote Mr. Teall's description of a specimen from Kentallen [1] (see Pl. XXIX, fig. 1):

'The rock [7053] [2] is composed of olivine, augite, biotite, plagioclase, orthoclase, magnetite, and apatite. The olivine is fresh, colourless, and is traversed by the usual anastomosing veins of magnetite. It is also, as a rule, crowded with extremely minute and often rod-like inclusions, which give it a cloudy aspect when viewed with low powers. The sections of the individuals are never bounded by straight lines meeting in sharp angles, but traces of idiomorphism are not uncommon; in other words, the mineral occurs as grains or as crystals with more or less rounded angles. It is present as inclusions both in augite and biotite, and the felspars are often moulded upon it.

'The augite occurs in grains, crystals, and patches, which vary in size—the largest often measuring several millimetres in diameter. The common crystalline forms may frequently be recognized, and the angles are often fairly sharp. The colour in thin slices is pale green, and sections which appear homogeneous in ordinary light often show a beautiful zonal structure under crossed nicols.

'Biotite occurs in small ragged patches, which, in spite of their apparent isolation, often show uniform orientation over large areas. The mineral is of a rich brown colour, approximately uniaxial, and strongly pleochroic. It is not only moulded on the augite and olivine, but also occasionally on the felspars, and was therefore one of the last minerals to form.

'The felspars, together with the small quantity of biotite, make up the interstitial matter in which the olivines and augites are embedded. Both plagioclase and orthoclase are present in approximately equal quantities, and the former is markedly idiomorphic with respect to the latter. The plagioclase sometimes shows a zonal structure, and probably ranges in composition from labradorite to oligoclase, the acid type predominating. It may be readily distinguished from the orthoclase by its higher refractive index and by the albite-twinning. The orthoclase occurs as interstitial matter (mesostasis). Individual patches sometimes show twinning on the Carlsbad plan. The accessory minerals are apatite and magnetite, the latter occurring almost exclusively in the veins which traverse the olivine. All the minerals are remarkably fresh.'

Passing to the area farther south-east, we find that the above description will apply equally well to sections prepared from specimens of the intrusions near Loch Avich [8287] [8568] and in Glen Orchy [8614] [8676]; see Pl. XXIX, fig. 2, & Pl. XXX, fig. 1. The Glen Orchy rock, however, appears to be rather richer in olivine and augite than that of Kentallen. The felspathic material is finer-grained, and, together with the biotite, plays the part of groundmass. This is especially well seen in the more marginal portion of the mass, where there is a sharp distinction between a groundmass of biotite and felspar and relatively large and conspicuous augites and olivines. A slide [8676] from another portion of this mass shows numerous phenocrysts of olivine and augite in a groundmass of biotite and felspar. The olivine is remarkably fresh, and is often seen to be bounded by crystal-faces: it occasionally occurs as inclusions in the augite. The augite is fresh, almost colourless, shows a beautifully defined crystal-form and zonal

[1] Ann. Rep. Geol. Surv. 1896 [1897] p. 22.

[2] The numbers in brackets throughout this paper indicate rock-sections in the Geological Survey collection at Jermyn Street, London.

structure between crossed nicols. While the olivine- and augite-crystals are of the same general size as those in the more central portion of the rock-mass, the texture of the biotite and felspar of the matrix has become much more fine-grained. The biotite occurs freely in scattered flakes, groups of which, on close examination, are seen to be in optical continuity, the appearance being similar to that of the biotite in the coarser specimens, only on a much smaller scale. Similarly, the biotite is seen to be of later formation than the plagioclase, which is markedly idiomorphic, and to be moulded upon it.

Biotite moreover occasionally occurs as inclusions in the augites, an occurrence which has also been noticed in the coarser rock both from this and other localities. Presumably it represents an earlier generation of the mineral, though there is no doubt that by far the larger proportion of the biotite was one of the last minerals to crystallize out.

Orthoclase, judging from the coarser rock, is presumably present as interstitial matter, but is difficult to identify with certainty, owing to the fine-grained character of the groundmass.

Passing now to the Ben-Bhuidhe area, we find that the olivine-bearing rocks of this group vary somewhat from the commoner type. They are rich in pyroxene, but do not contain quite so high a proportion of olivine as the Kentallen rock; while, on the other hand, the proportion of felspar, and especially of orthoclase, to olivine and pyroxene is decidedly higher.

Of the two masses, exposed in the Brannie and An-Sithein burns, that of Brannie Burn would seem to be slightly the more basic. The augite, olivine, and biotite of these rocks do not call for any further description, though it should be noted that the augite does not exhibit crystal-form anything like so perfectly as in the more typical rocks of this group, but tends to occur rather as corroded grains and granular aggregates. The characteristic ophitic structure of the biotite constitutes a pronounced feature in the Brannie rock [7414]. In a section of the An-Sithein rock [7415] (see Pl. XXX, fig. 2) the proportion of olivine is relatively small. The rock, however, is rich in pyroxene, and shows a slightly pleochroic hypersthene in association with the augite. But the most characteristic feature of both these rocks is the orthoclase-felspar: in the Brannie rock it occurs in approximately equal proportion with the plagioclase, but in the An-Sithein rock the orthoclase is decidedly in excess. It is pœcilitic in appearance, and forms a matrix of comparatively large, clear, irregular patches, in which small, lath-shaped, idiomorphic plagioclases lie embedded unorientated. With respect to the olivine and pyroxene, the orthoclase is interstitial. Individual patches occasionally show twinning on the Carlsbad plan.

We see, then, that in these Ben-Bhuidhe rocks the same peculiar features as those which have been already noticed in the more typical kentallenites are still found, and are represented in an even yet more

marked degree. The rocks are especially remarkable for a high proportion of orthoclase, in association with minerals such as olivine, augite, and hypersthene.

Reviewing the rocks of this class as a whole, from the areas above referred to, we see that our group consists of a graduated series, of which the more basic end is represented by the Glen-Orchy rock, and the less basic end by the rock of An Sithein, in the Ben-Bhuidhe area; while between these extremes comes the representative type of Kentallen and Loch Avich. At the more basic end we have a very high proportion of olivine and augite, while the proportion of orthoclase is relatively small, and is exceeded by that of the plagioclase. In the intermediate members of the group (Kentallen, etc.) the proportion of felspar to olivine and augite is found to have slightly increased, and the two felspars are present in approximately equal, though slightly varying, amount. Finally, at the less basic end of the series, represented by the Ben-Bhuidhe rocks, although there is still a high proportion of pyroxene, that of the olivine has decidedly decreased; while there is a marked increase in the proportion of the felspar, and in the An-Sithein variety orthoclase is in excess of plagioclase. In fact the An-Sithein rock might almost be designated a pyroxene-orthoclase-rock with olivine, biotite, and plagioclase. Thus, a progressive decrease in the amount of olivine is accompanied by a corresponding increase in the proportion of orthoclase.

This less basic example of the Ben-Bhuidhe varieties will at once recall the shonkinite of Messrs. W. H. Weed & L. V. Pirsson, and it will be of interest in this connexion to compare briefly the two rocks. Two occurrences of shonkinite were described in 1895 by those authors, from Montana, the one from Square Butte in the Highwood Mountains,[1] the other from Yogo Peak.[2] Occurring as part of a laccolitic intrusion in sedimentary strata of Cretaceous age, shonkinite forms a differentiation-product of a syenitic magma. It is essentially an augite-orthoclase-rock, with smaller amounts of olivine, iron-ore, biotite, and plagioclase, while apatite, and in the rock of Square Butte nepheline, cancrinite, and natrolite, occur as accessories. Olivine is not an essential constituent: it may or may not be present, while in the Ben-Bhuidhe rocks it plays by no means an unimportant part. The biotite is characteristic, and is pœcilitic with respect to olivine, augite, and iron-ore, being hence of later formation. Augite is the most important of the ferromagnesian constituents, and together with orthoclase determines the essential character of the rock: it occurs in well-formed crystals, which sometimes attain a length of 1 centimetre. The orthoclase is considerably in excess of the plagioclase, and occurs as broad plates in which, as in the An-Sithein rock, the plagioclase-

[1] Bull. Soc. Geol. Am. vol. vi (1895) pp. 400–22.
[2] Am. Journ. Sci. ser. 3, vol. l (1895) pp. 467–77.

laths lie scattered about unorientated. These broad areas of orthoclase not only contain the plagioclase, but also the other constituents in a pœcilitic manner.

In its chemical characters shonkinite is generally related to rocks of the basic class, low in silica, and high in magnesia, lime, and iron-oxide, and related to rocks of the lamprophyre-family. It stands very close chemically, as Messrs. Weed & Pirsson remark, to certain vosgesites and minettes, while differing from them in mineral composition and structure. It bears the same relation to augite-syenite that minette does to mica-syenite. The resemblance, therefore, between shonkinite and the rock of Allt-an-Sithein is still further of interest, in view of the evidence of the association in the Ben-Bhuidhe area of dykes and sills of lamprophyre with the kentallenite intrusions. These considerations, and the fact that the An-Sithein rock shows a marked variation from the more normal (Kentallen) type of the group, would naturally lead one to suppose that the chemical composition of the Ben-Bhuidhe rock would still further demonstrate on the one hand its affinities to such rocks as shonkinite, and on the other hand the points in which it differs from the Kentallen rock. A complete analysis was kindly prepared for us by Dr. W. Pollard, of the Geological Survey, with the following result:—

	Per cent.	
SiO_2	52·09	=100·24
TiO_2	·73	
Al_2O_3	11·93	
Cr_2O_3	·10	
Fe_2O_3	1·84	
FeO	7·11	
MnO	·15	
(CoNi)O	·07	
CaO	7·84	
MgO	12·48	
K_2O	3·01	
Na_2O	2·04	
CO_2	·16	
P_2O_5	·34	
Cl	trace	
H_2O	·35	

Specific gravity = 2·94

The result of the foregoing analysis fully bears out the observations made from the microscopic examination of the rock-section. The presence of chromic oxide probably indicates the occurrence of a small quantity of chromite or picotite, which is known to be of common occurrence in rocks rich in olivine, though it was not detected with certainty under the microscope. For the purposes of comparison, it will be sufficient to consider only the principal rock-forming oxides; and these we will compare with the published results of the analyses of the Kentallen rock, shonkinite, and the olivine-monzonite of Prof. Brögger, from Smälingen, in Sweden. We thus have the following table:—

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	52·09	48·00	48·49	46·73	50·35
Al_2O_3	11·93	12·52	12·29	10·05	15·76
Fe_2O_3 } FeO }	8·95	8·74	8·65	11·73	9·62
MgO	12·48	15·26	9·91	9·68	7·40
CaO	7·84	7·94	9·65	13·22	10·12
Na_2O	2·04	3·11	2·22	1·81	2·75
K_2O	3·01	2·68	4·96	3·76	3·89
Specific gravity ...	2·94	2·95	—	—	—

I. Kentallenite, Allt-an-Sithein, Glen Shira, Argyll. (Analysis by Dr. Pollard.) See Pl. XXX, fig. 2.

II. Kentallenite, Kentallen, near Ballachulish, Argyll. (J. J. H. Teall, Ann. Rep. Geol. Surv. 1896 [1897] p. 22.)

III. Shonkinite, Yogo Peak (Montana), U.S.A. (Weed & Pirsson, Am. Journ. Sci. ser. 3, vol. 1, 1895, p. 478.)

IV. Shonkinite, Square Butte, Highwood Mountains (Montana), U.S.A. (Weed & Pirsson, Bull. Geol. Soc. Am. vol. vi, 1895, p. 414.)

V. Olivine-monzonite, Smälingen, Sweden. (Brögger, 'Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol' p. 50.)

It will be seen that, with the exception of the silica and magnesia, there is a striking correspondence between the Allt-an-Sithein rock, that from Kentallen, and the shonkinite of Yogo Peak. The Allt-an-Sithein rock, being a slightly less basic variety, yields a higher silica- and lower magnesia-percentage than that of Kentallen, the microscope showing that it is richer in orthoclase and poorer in olivine. With the increase of orthoclase the relative proportion of the alkalis becomes reversed, the potash exceeding the soda, and this is also the case in both types of shonkinite and in olivine-monzonite. Both the Argyllshire rocks contain a considerably higher percentage of magnesia than shonkinite or olivine-monzonite, while the latter two are richer in lime, presumably owing to their relatively higher proportion of augite. Olivine cannot be considered more than an accessory in shonkinite and monzonite, while in kentallenite it is an essential constituent. The analysis fully bears out the petrological evidence that the rocks of Allt-an-Sithein and Kentallen belong to the same group,—a group of rocks with essential olivine and augite and smaller amounts of orthoclase and plagioclase in varying relative proportions. And these rocks show affinities (1) to the picrites, in their high proportion of augite and olivine; (2) to the shonkinites of America, in the peculiar association of those basic minerals with orthoclase-felspar; and (3) to the monzonites of Prof. Brögger, more especially to the basic variety of Smälingen, in the fact that orthoclase and plagioclase occasionally occur in approximately equal proportions, as in the rock of Kentallen.

The kentallenites of Argyllshire constitute another example, and one of the few known in Britain, of the peculiar association of orthoclase with olivine and augite. Besides the foreign examples of a similar association already referred to, we may cite that of the rock of Dignäs, in Norway, described by Brögger as a variety of olivine-

gabbro-diabase,[1] and now included in his monzonite-group. The rock contains accessory olivine and a small proportion of orthoclase.

Moreover, the occurrence of a considerable proportion of a rhombic pyroxene in addition to augite in the Allt-an-Sithein rock recalls certain hyperites and norites, in which orthoclase frequently occurs in addition to plagioclase, but without the association of olivine. Such are the hyperites, described by Mr. Teall,[2] associated with the Loch Dee granite of the Southern Uplands. These rocks show affinities to the so-called norites of Teller and Von John in the neighbourhood of Klausen in the Tyrol, and are essentially composed of plagioclase, hypersthene, augite, and biotite, with small quantities of quartz and orthoclase occurring as interstitial matter. Among the Cortlandt Series of the Hudson River the norite proper, described by G. H. Williams,[3] consists mainly of andesine and hypersthene, with accessory biotite; and an interesting feature is the occurrence of large crystals of orthoclase enclosing the other minerals in a pœcilitic manner: the hypersthene may be associated with augite, and sometimes hornblende. Then, again, in the Lake-Superior region we have the 'orthoclase-gabbro' of Irving,[4] in which the plagioclase is oligoclase or an allied variety, and orthoclase occurs in addition.

It is interesting to note that in many of these basic rocks which are characterized by the occurrence of orthoclase, the plagioclase-felspar belongs rather to the more acid series than to the more basic; that is to say, one frequently finds felspars of the oligoclase-andesine variety rather than those of the labradorite-anorthite series, which one would more naturally expect in rocks of thoroughly basic character. Thus in the shonkinite of Yogo Peak the plagioclase is andesine; in the olivine-monzonite of Smälingen it is andesine as well as labradorite. We have andesine again in the norite of the Cortlandt Series, and oligoclase, or an allied variety, in the 'orthoclase-gabbro' of the Lake-Superior region; while in kentallenite the plagioclase 'probably ranges in composition from labradorite to oligoclase, the acid type predominating.' We may further note in this connection that in kentallenite the plagioclase, orthoclase, and biotite, together play the part of groundmass to the olivine and augite, a feature especially well brought out in the variety of the Glen-Orchy rock already described (p. 534). (We thus have an earlier generation consisting essentially of olivine and augite, and a later consisting of a more or less acid plagioclase, orthoclase, and biotite. The chemical composition of this groundmass would probably approximate to that of a mica-diorite, when plagioclase was in excess of orthoclase, and would probably resemble closely that of many of the relatively more acid rocks of the same district, while the earlier-formed constituents would be of ultrabasic com-

[1] Brögger, 'The Eruptive Rocks of Gran' Quart. Journ. Geol. Soc. vol. l (1894) p. 19.
[2] Ann. Rep. Geol. Surv. 1896 [1897] pp. 41 & 42.
[3] Am. Journ. Sci. ser. 3, vol. xxxiii (1887) pp. 135–44, 191–94.
[4] U.S. Geol. Surv. Monogr. no. 5 (1883) pp. 50–56.

position. And, moreover, since the relative proportions of the two felspars in kentallenite vary considerably, the composition of the groundmass, or second generation, of the different varieties would range from that of a mica-diorite to a mica-syenite, the intermediate stage being typical of the monzonite-group of Prof. Brögger. These considerations are strongly in favour of the origin of these and similar basic rocks by a process of magmatic differentiation, in which progressive crystallization was the principal determining factor.

Finally, it is perhaps not unworthy of note that the characteristic behaviour of the orthoclase is common to many of the different types of this class of basic rock and their less basic allies. It occurs frequently in broad patches which enclose the earlier formed minerals, especially the plagioclase, in a well-marked pœcilitic manner. This is well seen, as we have already pointed out, in the kentallenites of the Ben-Bhuidhe area, in shonkinite, and in the olivine-monzonite of Smälingen. It is again exemplified in the norites of the Cortlandt Series and in the monzonites (augite-syenites) of Southern Tyrol.[1] We have not noticed it in any of the Argyllshire intrusions of less basic type than kentallenite, but it is exceedingly well shown in a rock recently collected by our colleague Mr. J. Grant-Wilson, forming a marginal facies to the Ben-Nevis granite, and showing close relationships to the Monzoni type. This latter case is of interest, in that the main mass of the Ben-Nevis granite closely resembles that of Ballachulish and Ben Cruachan, so that it would not be unreasonable to expect the occurrence of rocks belonging to the Kentallen or Shonkin type in the Ben-Nevis area.

Summarizing briefly the more general petrological features of the rocks under consideration, we may say that kentallenite belongs to a peculiar class of basic rocks, of extremely local occurrence, but now becoming more generally recognized, in which orthoclase and an intermediate or acid plagioclase are associated with such basic minerals as olivine, augite, and sometimes also hypersthene, biotite being also generally present; and these rocks include such types as the shonkinite of Montana and the olivine-monzonite of Scandinavia.

More particularly speaking, kentallenite may be defined as a rock consisting of essential olivine and augite, with orthoclase and plagioclase in varying proportions, and biotite. Hypersthene may occasionally occur in addition to augite, and the biotite is of later formation than the plagioclase. With a decrease in the proportion of olivine, the proportion of orthoclase rises, frequently exceeding that of the plagioclase, and exhibits a micropœcilitic structure. Chemically, so far as is yet known, the silica-percentage ranges from 48 to 52. Magnesia may be as high as 15·26 per cent., while the relative proportions of the alkalis vary. We will now deal with the more special relationships of these rocks to the other intrusions with which they are associated in the field.

[1] See Brögger, 'Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol' Kristiania 1895, pp. 56 & 57, figs. 1 & 2.

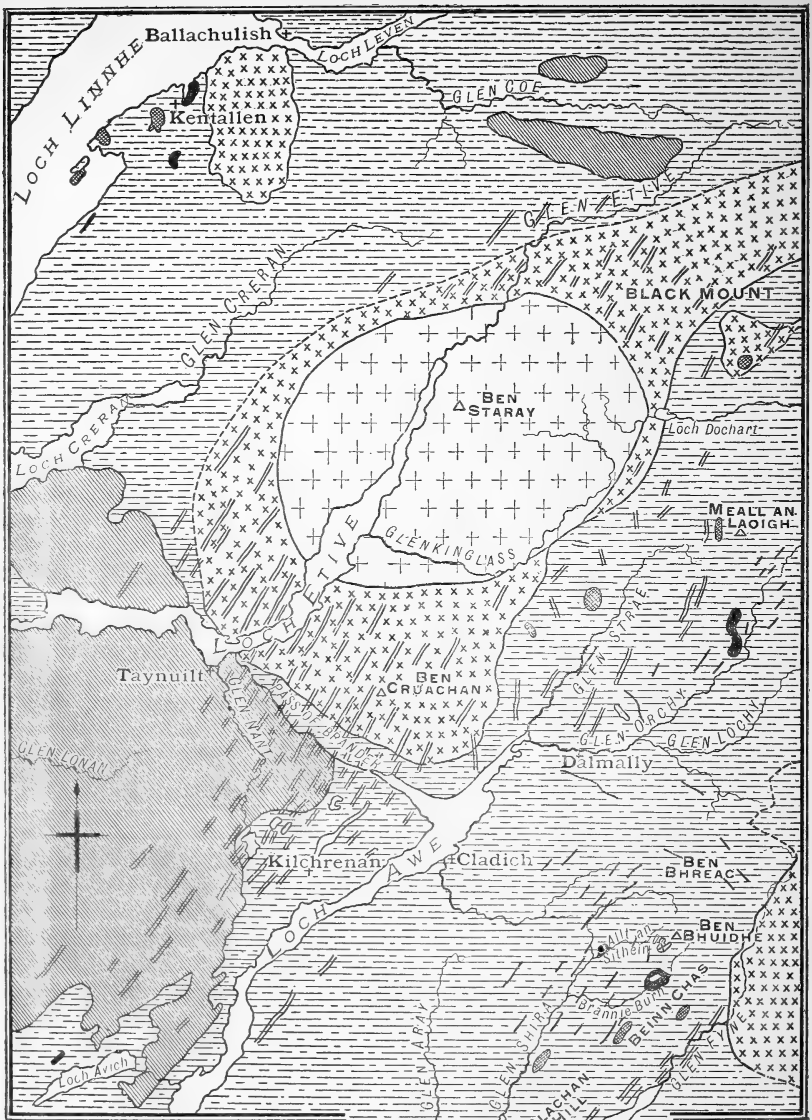
III. The Relation between the Kentallenites and the Granites and Diorites. (See Map, p. 542.)

As we have already pointed out, kentallenite invariably occurs in areas which have been invaded by various intrusive rocks such as granite, diorite, lamprophyre, etc. And, moreover, one may see at a glance that that portion of Argyllshire over which kentallenites are distributed, naturally divides itself into four intrusive areas, at no great distance one from the other. Thus we have (1) the Ballachulish area, characterized by the Ballachulish granite, various diorites and allied intrusions, and the basic rock of Kentallen; (2) the Ben-Cruachan area, characterized by the enormous granite-masses of Ben Cruachan and Glen Etive, augite-diorites, and numerous sills and dykes of porphyrite, to which we may add the kentallenite-intrusion of Glen Orchy; (3) the very much smaller area of Loch Avich, characterized by several small granitic intrusions, recently mapped by our colleague Mr. R. G. Symes, in the neighbourhood of Kilmelfort, and the kentallenite exposed to the west of Loch Avich; and lastly (4) the Ben-Bhuidhe area, characterized by intrusions of granite, tonalite, augite-diorite, numerous lamprophyres, and the olivine-augite-orthoclase rocks of the Brannie and An-Sithein burns.

It would be beyond the scope of this paper to enlarge upon the various features which these four areas possess in common. It will be sufficient for our purpose to emphasize the fact, already indicated above, that in each area there is on the whole a generally similar assemblage of intrusive rocks, whose basic representative is in each case almost identical.

The inference seems obvious, therefore, that the development of the basic type took place under conditions almost identical in each area. Further, in each case, the various intrusive types appear to be so closely related one to the other, that we believe that they represent the products, during different phases of activity, of a common parent-magma. But until the ground had been surveyed in detail, the relationship of the kentallenites to the other intrusions did not seem particularly clear. We are now, however, able to present evidence, which shows that this particular group bears as close a relation to some of the diorites, as the diorites themselves bear to the granites. The greater part of our material has been derived from field-observations in the Ben-Bhuidhe area, supplemented by the microscopical investigation of numerous sections prepared for the Geological-Survey collection from our specimens.

It is in the Ben-Bhuidhe complex of igneous rocks that the relationships of the kentallenites are perhaps most clearly shown. We shall therefore, in what follows, deal more particularly with that area. We believe, at the same time, that similar relationships are also indicated in the other Argyllshire areas where our basic type occurs, and that, although the evidence which they furnish may not be so complete, they will abundantly confirm the conclusions that we have drawn from a comparative study of the Ben-Bhuidhe rocks.



SKETCH MAP OF A PORTION OF ARGYLLSHIRE,
illustrating the distribution
OF KENTALLENITE,
and its associated intrusions.
by J. B. Hill & H. Kynaston.

Scale:– 1 inch = about $5\frac{1}{3}$ miles.

Granite — Granite of Glen Etive — Diorite (Tonalite, Aug.-Diorite, &c.) — Kentallenite — Andesitic lavas — area of Crystalline Schists

// .... Dykes & Sills of Porphyrite with some Quartz-Porphyries & Orthophyres.

/ .... Dykes & Sills of Lamprophyre.

The Ben-Bhuidhe area covers a mountainous tract to the west of Glen Fyne, and between that glen and Glen Shira. In its more central portion Ben Bhuidhe forms a well-defined ridge, rising to slightly over 3000 feet above sea-level. On this ridge occur two somewhat irregularly-shaped masses of granite, of a medium-grained and rather acid type, resembling some of the finer-grained portions of the Glen-Fyne intrusion. In dealing with these granites it must be borne in mind that they are undoubtedly related to the far larger intrusive mass of Glen Fyne, and doubtless constitute subordinate modifications of the same magma. The intrusions on Ben Bhuidhe are not more than 2 miles from the nearest exposure of the Glen-Fyne mass, and there are close petrological relationships between them.

These granites represent the more acid intrusions of the Ben-Bhuidhe complex. Between them and our most basic type, represented by the kentallenites of the Brannie and An-Sithein burns, come several intrusions of more intermediate type, such as augite-diorite and tonalite, which we regard as constituting connecting-links between the two extremes. In addition to these we find numerous lamprophyres of varying type, especially well-developed in Glen Shira, representing the more basic end of the series in terms of dykes and sills; while the more acid end is represented by porphyrites and orthoclase-porphyries, more especially developed in and about Glen Fyne. We have, then, in the Ben-Bhuidhe area an assemblage of intrusive rocks—on the one hand belonging rather to the boss-like or laccolitic type of intrusion, and ranging from granite to olivine-augite rocks containing orthoclase; and on the other hand belonging to the dyke- or sill-phase, and varying from orthoclase-porphyries to basic lamprophyres.

A mass of diorite of evidently basic affinities is well exposed $\frac{1}{2}$ mile north-west of Clachan Hill, and about $\frac{3}{4}$ mile from the olivine-augite-rock of Brannie Burn. It forms an elongated sill-like mass, about $\frac{1}{2}$ mile long and $\frac{1}{8}$ mile broad, on the steep slope between the Clachan-Hill ridge and Brannie Burn; and from its dark aspect and rugged mode of weathering, the rock at first sight recalls kentallenite. A closer inspection, however, at once shows that we are dealing with a less basic type. The rock is almost black in hand-specimens, and augite, biotite, and felspar may be seen with a lens. An occasional, though rare, grain of what is apparently olivine may also be detected. Under the microscope [8461], the rock is seen to be composed of nearly colourless augite, biotite, green hornblende, plagioclase, and a little interstitial quartz. A very small amount of orthoclase-felspar may also be detected, occurring interstitially. The rock is somewhat altered, and carbonates are present. Olivine is occasionally seen in the form of inclusions in the augite.

Comparing this rock with our more basic type of the Brannie and An-Sithein burns, we find that olivine is decidedly rare. The rock, however, is rich in augite, and the mineral is of the same variety as that characteristic of the An-Sithein and Brannie rocks. The biotite

also occurs in characteristic ragged plates, and is of late formation. We perceive, however, that hornblende has appeared, plagioclase is plentiful, and the proportion of orthoclase-felspar has dwindled to an exceedingly small amount. The rock may be classed as an augite-diorite, showing affinities on the one hand to kentallenite, in the occasional presence of olivine, the character of the augite, the behaviour of the biotite, and the presence of a small amount of orthoclase; and on the other hand to diorites of the tonalite-type, in the presence of plagioclase, hornblende, and a certain amount of interstitial quartz.

A fairly similar rock is found forming part of a small intrusion ½ mile south of Beinn Chas, on the ridge between the head of Brannie Burn and Glen Fyne. It appears to form the more marginal portion of the intrusion, and to pass, towards the more central portion, through a diorite of the tonalite-type into biotite-granite. The intrusion itself is about ¼ mile long and ⅛ mile broad, and is situated rather over a mile from the boundary of the main mass of the Glen-Fyne granite, though a marginal area of schist extensively veined by granite approaches it to within ⅓ mile. A specimen from near the margin of this mass is a dark-grey fine-grained rock of dioritic appearance. Under the microscope [7413], see Pl. XXXI, fig. 1, augite is seen to be plentiful in more or less idiomorphic crystals and rounded grains. Biotite appears as small ragged flakes, and behaves in the same way as the biotite of the Brannie and An-Sithein rocks. The rest of the rock consists of small lath-shaped plagioclases, interstitial orthoclase, and a small amount of quartz. There is also some accessory magnetite, and some secondary green hornblende and chlorite in association with the pyroxene. There is no olivine. This rock is evidently a variety of augite-diorite, resembling that already described from the neighbourhood of Clachan Hill, and bearing relationships, borne out by the high proportion of pyroxene, the behaviour of the biotite, and the presence of interstitial orthoclase, to our basic rocks of the Brannie and An-Sithein burns. The entire absence of olivine separates it from our kentallenite-group, and brings it a step nearer to the diorites of this district. At the same time, the presence of orthoclase allies such rocks as these with the syenites, and especially with the typical monzonites (augite-syenites) of the Tyrol.

Another specimen from the margin of the same mass [8637] rather tends to show that a basic modification, exactly resembling the rock just described, does not necessarily constitute an uniform zone along the entire edge of the mass, but rather that the margin may be less basic in some parts than in others, the different varieties shading imperceptibly one into the other. We see in this specimen that the proportion of augite has become relatively small, that there is still less idiomorphism in the crystals, and that they are often partly replaced by green fibrous hornblende. Augite, in fact, has sunk to the level of an accessory constituent, while the main mass of the rock consists of numerous small idiomorphic plagioclases, small biotite-flakes, green hornblende, and interstitial orthoclase and

quartz. As we pass from this marginal area into the more central and slightly coarser part of the mass, the rock is seen to diminish gradually in basicity. Thus slightly nearer the centre we have a *quartz-diorite or tonalite* [8635], see Pl. XXXI, fig. 2, consisting of green hornblende, biotite, idiomorphic plagioclase, and interstitial orthoclase and quartz; while the central portion itself consists of a medium-grained *biotite-granite*, with biotite alone representing the ferromagnesian constituents [7412].

Thus we find in this one small intrusion a perfectly clear and gradual transition from a rock rich in pyroxene, and undoubtedly allied to our still more basic types, to an acid biotite-granite. The pyroxene dies out from the margin inward, while hornblende makes its appearance, gradually becoming an important constituent, and the proportion of orthoclase perceptibly rises. Finally, as we approach the centre of the mass, the hornblende disappears, the biotite persists, and the proportion of orthoclase is still further increased; and we have a biotite-granite, similar to the more acid granites of Ben Bhuidhe and some of the finer-grained varieties of Glen Fyne. The transition from one type to the other is on the whole gradual, but is more rapid near the margin where the pyroxene-bearing zone commences; that is to say, the passage is rather more gradual between granite and tonalite, than it is between tonalite and augite-diorite. There can be no doubt whatever of the genetic relationships of the different varieties—for here is a mass showing a progressive increase in the proportion of ferromagnesian minerals from centre to margin, accompanied by a decrease of orthoclase and quartz.

We will not discuss here the particular type of differentiation which is illustrated by this intrusion: what we wish more particularly to point out in this connexion is the relationship which evidently exists, not only, as this mass alone shows, between granites of the Ben-Bhuidhe type and the augite-diorites (containing interstitial orthoclase) of the same area, but also between these granites and our more basic rocks rich in olivine and augite. Thus, we have already pointed out the relationship between the kentallenites of the Brannie and An-Sithein burns and augite-diorites, such as that of the Clachan Hill; and we have now described a case of an almost precisely similar variety of augite-diorite actually passing by intermediate stages into a granite, within the limits of a single small intrusion. We believe then, from the evidence supplied by a study of these small intrusions in the Ben-Bhuidhe area, that *there are genetic relationships between the remarkable group of rocks which we have called kentallenites, and biotite-granites and tonalites of the Ben-Bhuidhe and Glen-Fyne type.*

Let us now see whether in the neighbouring eruptive centres we have any evidence which will confirm the conclusions arrived at in the Ben-Bhuidhe area.

In the outlying portions of the region which has been invaded by

the huge granite-mass of Ben Cruachan, we find several intrusions of a well-marked variety of augite-diorite situated at no great distance from the margin of the granite. A mass of this diorite is well exposed on Ben Lurachan, between Glen Strae and Glenkinglass. One or two smaller masses occur in the same neighbourhood, and the rock is again well seen on Meall-an-Laoigh, between the head of Glen Strae and Glen Orchy. In their mode of intrusion these diorite-masses resemble kentallenite, that is to say, they behave rather as small bosses and broad lenticular sills. In colour the rock is dark grey, the augite being very conspicuous, and generally marked off sharply from the more felspathic portion, so as to give the rock a characteristic spotted appearance. A bronze-brown biotite is also easily distinguished by the unaided eye. Specimens from Meall-an-Laoigh [8622], Ben Lurachan [7760], and Meall Copagach [7761], in the same neighbourhood, were examined under the microscope.

The augite occurs in relatively large and perfectly idiomorphic crystals, and closely resembles the augite of the kentallenite of Glen Orchy. The margin of the pyroxene is frequently seen to be replaced by a border of green hornblende. Hornblende is also seen to occur as an original constituent, and to be of a variety similar to that observed in the granite and diorite of Ben Cruachan, etc. The rest of the rock consists of biotite, plagioclase, orthoclase, and quartz. The biotite occurs in ragged patches and groups of detached flakes in optical continuity, a feature already noticed as characteristic of kentallenite. Similarly, it is of later formation than the plagioclase, which is markedly idiomorphic. The orthoclase and quartz are interstitial. Apatite and iron-ores occur as accessories. The orthoclase is well seen in the rock of Ben Lurachan and Meall Copagach; it is only present, however, in very small proportion in the Meall-an-Laoigh rock.

There seems to be strong evidence, therefore, of the relationship between these rocks and the kentallenite of Glen Orchy. The augite and biotite are of the same variety and behaviour, and orthoclase occurs interstitially. In fact, in the Meall-an-Laoigh rock, if we could replace the hornblende by olivine, we should have a kentallenite of the Glen-Orchy variety; while the rocks of Ben Lurachan and Meall Copagach approach more nearly the type of Kentallen in their higher proportion of orthoclase-felspar. Again, it can hardly be doubted that these diorites are closely associated with the larger granitic intrusions of Ben Cruachan, finding as we do within the Ben-Cruachan mass an actual transition from augite-diorite to hornblende-granite.[1] Thus, in this area again we find a dioritic rock, occurring in well-individualized intrusions, showing affinities to the kentallenites of the same area, while a similar diorite is seen to occur as part of the Ben-Cruachan mass.

In the Loch-Avich and Kilmelfort area several small granitic intrusions have been mapped by our colleague Mr. R. G. Symes, and

[1] Summ. Progr. Geol. Surv. for 1897 [1898] p. 86.

we have already drawn attention to the occurrence of kentallenite in the same area. The granitic intrusions consist of biotite-granite, quartz-diorite, and augite-granite. One exposure of augite-granite is not more than $2\frac{1}{2}$ miles from the Loch-Avich kentallenite. It occurs on the northern shore of Loch-a-Chaoruinn, about $1\frac{1}{2}$ miles west-north-west of the head of Loch Avich. The other intrusions are found farther westward, east and south-east of Kilmelfort.

The augite-granite consists of an almost colourless augite, pale green hornblende, biotite, plagioclase, orthoclase, interstitial quartz, and accessory magnetite [8566 & 8575]. The plagioclase is largely in excess of the orthoclase. In the quartz-diorite [8571] we find a brown idiomorphic hornblende, resembling the variety characteristic of camptonite.

Here again we have a similar assemblage of intrusive rocks, though the transitional varieties are not so numerous. It is interesting to note, however, that here also the association of a pale augite and interstitial orthoclase characterizes other and more acid intrusions than those of the basic type of Loch Avich, thus serving to connect the basic type with the diorites and granites.

Passing now to the Ballachulish area, we find west and south-west of the granite-mass of Ballachulish, besides the intrusions of kentallenite already described (pp. 533–34), three intrusions of augite-diorite, which have been mapped by Mr. J. Grant-Wilson. They occur, as may be seen by a glance at the sketch-map (p. 542), at no great distance from the granite-margin:—at Ardshiel Hill, less than a mile south-west of Kentallen; at Rudha Mor; and on Eilean Balnagowan. The rocks are referred to as follows in the Annual Report of the Geological Survey for 1896, pp. 21 & 22:—

'The rock of Eilean Balnagowan is a diorite with a somewhat exceptional amount of orthoclase, and possessing, therefore, affinities with the syenites; that of Rudha Mor is a quartz-augite-diorite; and that of Ardshiel Hill an augite-diorite, with a small amount of quartz. All these rocks contain a small quantity of interstitial quartz and alkali-felspar; a fact which shows that they are merely basic modifications of the magma which has produced the larger granite-masses of Ballachulish and Ben Nevis.'

We have examined these rocks under the microscope, and were at once struck with the resemblance between them and the augite-diorites, described on p. 546, from near Glen Strae in the Ben-Cruachan area. The granite-mass of Ballachulish, moreover, closely resembles that of Ben Cruachan, and varies from diorite to hornblende-granite, becoming on the whole more acid as we approach the inner portion of the mass. Here, then, is a marked repetition of similar phenomena. We cannot dissociate the augite-diorites from the granite, while on the other hand there is strong evidence of the former being related to the more basic kentallenites; and we cannot but conclude that the evidence, which is so well brought out by a comparative study of the Ben-Bhuidhe rocks, is strongly confirmed in the other granitic centres of Ben Cruachan, Loch Avich, and Ballachulish.

IV. The Relation between the Kentallenites and the Lamprophyres.

We have already referred to the occurrence in the Ben Bhuidhe area of numerous lamprophyres, which are found mostly in the form of narrow sills intrusive in the older schistose rocks. These sills are especially numerous on the Glen Shira side of Ben Bhuidhe, but become far less common as we go westward from Glen Shira. They are thus of more common occurrence in the tract characterized by the kentallenite and augite-diorite intrusions. These rocks are by no means all of one type, but show considerable variation in composition, ranging from basic augite-lamprophyres through various varieties of camptonite to a hornblende-lamprophyre approaching hornblende-porphyrite. Biotite also, as well as hornblende, frequently plays a prominent part in these rocks, and thus biotite-camptonites and various micaceous lamprophyres may also be met with.

A microscopic study of a large number of these rocks has convinced us that there are close relationships between the more basic augite-bearing varieties of the group and the larger intrusive masses of kentallenite and augite-diorite. Let us take one or two examples of some of the more basic varieties of these sills. Two small lamprophyre-intrusions of this type occur on the slopes of Ceann Garbh, about 2 miles north-east of Ben Bhuidhe. These sills are similar in appearance, and consist of a medium-grained dark-grey rock, in which augite and some plagioclase-crystals may be seen to occur porphyritically. Under the microscope [7416 & 7417] a section is seen to consist of fairly numerous and relatively large phenocrysts of augite, and a few phenocrysts of plagioclase, in a groundmass which is mainly felspathic. The augite is idiomorphic, colourless, and frequently shows a well-marked zonal structure.

The groundmass consists mainly of small lath-shaped plagioclases, small augite-grains, irregular flakes of biotite, and chloritic alteration-products. There is a very small quantity of interstitial quartz, and magnetite is accessory. Although there is no original hornblende in these rocks, yet there is a striking family resemblance between them and the variety of augite-diorite already described, occurring on Clachan Hill, and also to the more basic marginal portion of the dioritic intrusion of Beinn Chas. There can be very little doubt that they represent the dyke-phase of the same magma, or of a similarly differentiated portion of it, as that which produced these more basic dioritic types; and we have already pointed out the close relationships that exist between these latter intrusions and the kentallenites of the Brannie and An-Sithein burns. Although the peculiar and essential characters of kentallenite can scarcely be said to be represented in these sills, yet their intimate association with the more basic intrusions of the area leaves little uncertainty as to the existence of relationships between them. No doubt kentallenite represents a more specialized product of the original common magma.

Between these basic lamprophyres rich in augite and the typical camptonites of the Ben-Bhuidhe area, every gradation may be traced, by an inspection of the numerous sills. Thus in some sills we find that the proportion of augite is comparatively small, while a brownish hornblende of the type characteristic of camptonite makes its appearance, and the proportion of felspar rises. A sill occurring about a mile south of Meall-an-Tighearn illustrates this transition. A section [8834] shows a few chloritic pseudomorphs after augite, brown hornblende in acicular prisms, more or less idiomorphic plagioclase, and a small quantity of interstitial quartz. The proportion of biotite varies greatly in these sills, but its absence is unusual. With the increase of hornblende the augite disappears, and we find variations of the camptonite-type, which are exceedingly common. An example, which perhaps shows a higher proportion than usual of ferro-magnesian constituents, occurs $\frac{1}{2}$ mile west of Clachan Hill, close to the mass of augite-diorite. It may be termed a biotite-camptonite, and is rich in both biotite and hornblende [8462]. With a decrease in the proportion of these minerals we have more typical camptonites, and hornblende-lamprophyres in which hornblende is conspicuously porphyritic; and these latter, by the advent of porphyritic plagioclase and an increase in the felspar of the groundmass, pass over into hornblende-porphyrites.

In the Ben-Cruachan area similar gradations among the lamprophyre-sills may be observed. The lamprophyres are here more common in the eastern portion of the area, and numerous varieties of the camptonite-type are exceedingly abundant in Glen Orchy.

As an example of the more basic end of the series, we may cite a well-marked sill occurring about $\frac{1}{2}$ mile south-east of Dalmally Hotel. It consists of a medium-grained, dark-grey rock. Under the microscope [8464] the rock is seen to resemble the augite-lamprophyres of Ceann Garbh, near Ben Bhuidhe, and the augite-diorite, allied to kentallenite, of Clachan Hill. It is exceedingly rich in pyroxene, while the proportions of biotite and felspar appear to vary in different parts of the sill. The augite is plentiful: it is almost colourless, and frequently shows well-marked idiomorphism. Besides the augite, one notices also fairly numerous brownish phenocrysts resembling bastite-like pseudomorphs after enstatite. There is no hornblende. The biotite occurs mostly in irregularly-shaped elongated flakes, which are seen to be moulded on the plagioclase, and therefore of later formation. The plagioclase occurs occasionally as idiomorphic porphyritic individuals, which are usually rather decomposed, and as more or less lath-shaped individuals in the groundmass. Interstitially there is a small amount of quartz. A very small quantity of orthoclase may be present, but owing to the decomposition of the felspars it is difficult to identify the mineral with certainty. Occasionally one may see an interstitial substance bordering some of the plagioclase-crystals, and showing a minute more or less fibrous structure, suggestive of micropegmatite.

As in the Ben-Bhuidhe area, so here we may trace the connexion between these basic sills and the camptonites through intermediate

varieties. Thus in Glen Strae occurs another basic lamprophyre [5539], which does not show nearly so high a proportion of augite as the rock above described; while brown hornblende has made its appearance, and exhibits the elongated prisms characteristic of camptonite. Again, a sill occurring 1 mile north of Craig House, Dalmally [8459 & 8615], is a fairly typical camptonite, which appears only occasionally to contain augite in the more basic portions of the sill [8459]. Similar camptonites, without augite, and various closely-related hornblende-lamprophyres are common in the Glen-Orchy area [8677, 8678]. Thus the Ben-Cruachan area also furnishes strong evidence of the close relationships between our more basic lamprophyres and the augite-diorites with affinities to kentallenite on the one hand, and the camptonites on the other hand. Similarly we might describe transitional varieties between the hornblende-lamprophyres and the porphyrites, the numerous sills of which are so characteristic a feature of both the Ben-Cruachan and Glen-Fyne areas; and there can be no doubt that these porphyrites represent the dyke- or sill-phase of the larger masses of hornblende-granite. In short, the evidence afforded by the occurrence of these numerous connecting varieties enables us to bind an assemblage of intrusions, consisting of a large number of rock-types, into one connected whole.

Before leaving the lamprophyres, we would refer briefly in this connexion to the sill, described on p. 546 as augite-diorite, on Meall-an-Laoigh, near the head of Glen Strae. While the main mass of this sill may fairly be referred to augite-diorite, the central portion consists of a hornblende-lamprophyre of a type by no means common in this district. The passage between the two kinds of rock is somewhat sudden, yet the lamprophyre can scarcely be regarded as a distinct intrusion, as it has no fine-grained margin, and the characteristic idiomorphic augites of the dioritic type are still seen to occur, though less abundantly. The lamprophyre frequently veins the diorite in an intricate manner, and the two types are often so intermingled, that they cannot be otherwise regarded than as portions of the same mass.

A section of the lamprophyric type is seen under the microscope [8946] to consist mainly of elongated prisms of greenish-brown hornblende and alkali-felspar. The hornblende is of the same type as that so characteristic of many of the camptonites of the same area. The alkali-felspar constitutes a granular aggregate, forming as it were a background in which the hornblende-prisms lie embedded. Occasionally a larger patch of hornblende is seen to constitute a pseudomorph after augite. There is some plagioclase, but the orthoclase is largely in excess. Sphene and apatite are accessory, the former being of the same variety as that found in the augite-diorite. The rock apparently belongs to the syenitic lamprophyres, and since it consists essentially of alkali-felspar and hornblende, may be referred to vosgesite. The intimate association of these two types of rock in one mass leaves no doubt as to the close genetic relationships between the augite-diorites and the lampro-

phyres; and the decided syenitic tendency of the central portion of this sill is doubly interesting, in connexion with the relationships which we have shown to exist between such augite-diorites and kentallenite.

V. General Considerations.

In the foregoing pages we have described the principal varieties of kentallenite, hitherto known as occurring in Argyllshire; we have endeavoured to indicate their petrological affinities, and have pointed out their relationships to the granites, diorites, and lamprophyres of the areas in which they occur. It now remains briefly to refer to a few considerations of a more general nature.

From a study of the intrusive rocks of the Ben-Bhuidhe area, we cannot avoid the conclusion that the various intrusive types, from kentallenite to granite, constitute a closely-related assemblage, which have all been derived from an original common magma. The evidence which we have brought forward as to the inter-relationships of the different rocks, is strongly confirmed in the other areas where kentallenite occurs. And these areas have, petrographically, so many features in common with that of Ben Bhuidhe, that we are led to infer that what has taken place in the one area has also taken place in the other. From a petrographical standpoint, we may subdivide the general district,—as we have already done for the sake of convenience in description,—into secondary areas of intrusion, or eruptive foci, each characterized by important masses of acid material, about which secondary intrusions of more basic character are apparently arranged as about a nucleus. In each area, differentiation has evidently followed along parallel lines. The physical conditions have been approximately similar, and similar rock-types and similar phenomena of intrusion have been the result. From this, one is naturally led to suppose that the original magmas of each eruptive centre resembled one another more or less closely in chemical composition. Is it not then extremely probable, considering the comparative proximity of the different centres, that the sources of supply for each proceeded from one parent-magma? We must suppose that the reservoir for each centre owed its origin either to a more deep-seated general magma, or to the splitting up by some means, such as crust-movement, of one large magma into secondary reservoirs, while it was still more or less homogeneous.

Since the phenomena of intrusion are more or less similar in each centre, we may confine ourselves to the Ben-Bhuidhe area in dealing shortly with the remaining points which call for attention. Owing to the close relations existing among the various rock-types which constitute the Ben-Bhuidhe complex, it is evident that they belong to the same general geological period, but at the same time it would be of interest if some definite sequence among the different intrusions could be established. The evidence, such as it is, appears to show that the kentallenites represent the earliest intrusions of this area. The mass exposed in the An-Sithein burn is seen to be cut by

a lamprophyre-sill, while the mass exposed in Brannie Burn has been invaded by a later intrusion of a granite closely resembling that of Ben Bhuidhe. This granitic intrusion is well seen in a tributary burn flowing into the Brannie from the flanks of Ben Bhuidhe, and granite is exposed in the bed of the burn for a distance of 170 yards. There can be no doubt of its intrusive character, the rock being distinctly fine-grained at its contact with the kentallenite, and gradually becoming coarser as one proceeds farther into the mass. Veins also of the granite are seen to penetrate the kentallenite. The actual outline of the intrusion cannot be determined, as, on either side of the burn, it is hidden by morainic material.

Again, a lamprophyre-sill, which must be referred to the same group as that cutting the Allt-an-Sithein kentallenite, and occurs on the northern flanks of Ben Bhuidhe, is seen to be distinctly veined by the granite, close to the main mass of which it is exposed, while the microscope shows that distinct contact-alteration has taken place. A section taken close to the contact with the granite-vein shows that the lamprophyre now consists essentially of small scales of contact-brown mica and water-clear plagioclase [8467]. Slightly farther from the vein [8468] there are still signs of contact-action, while the original crystals and crystalline aggregates of the hornblende of the lamprophyre may be seen. Mr. Teall, who has kindly examined these slides, remarks that 'these specimens seem to remove all doubt as to the contact-metamorphism of the lamprophyres.' We have therefore clear examples of a lamprophyre cutting kentallenite, and of a lamprophyre being in its turn cut by granite, while a granite of similar type again cuts kentallenite. This, then, will give us the sequence—kentallenite, lamprophyre, granite, in order of intrusion. In other words, this evidence shows that in the Ben-Bhuidhe area, more acid material followed the intrusion of basic. This conclusion is borne out by the fact that both the kentallenite-masses of this area are traversed by a band or vein of felspathic material, representing the more acid portion of the underlying reservoir. Whether this process was continuous or not, we have no means of determining in respect to the general area under consideration; locally, however, the phenomenon of acid veins in the basic rocks shows that this was not always progressively continuous.

It is very probable, moreover, that basic material may still have existed and have been intruded, during the later phases of intrusive activity; since in certain other of our Argyllshire centres we find sills, belonging to the camptonite-group, cutting the larger granite-masses, and moreover, in the Ben-Cruachan area, we find basic dykes allied to basalt, cutting the latest and most acid portion of the granite. From the single case of a lamprophyre being veined by granite in the Ben-Bhuidhe region, we are hardly justified in concluding that all the lamprophyres are older than the granite. It may well be, judging from the evidence of other areas, that some are older, while others again are younger.

It is interesting, however, in this connexion to note that our conclusion, that in the main, acid material followed basic, is strongly

confirmed by the researches of Messrs. Dakyns & Teall among the granitic rocks of Garabal Hill and Meall Breac,[1] and these rocks form the continuation to the south-east of the Glen-Fyne granite. From this interesting region the above-mentioned authors have described a series of rocks, forming portions of a continuous mass, ranging from peridotites to granite. They find that the first rocks formed were the peridotites, and then followed diorites, tonalites, and granites in the order of increasing acidity. The more basic rocks occupy a position which is marginal with respect to the more acid. This would also appear to be the case among the intrusions of the Ben-Bhuidhe area. It may be said, generally speaking, for this area, that the more distant any intrusion is from the granite, the more basic will be its character, so that we find the kentallenites tending to occupy the outer zone of eruptive activity. While, on the whole, more basic material is invariably marginal in its position with regard to more acid, it would not be possible, owing to local exceptions and variations in the nature of the intrusions, to map out any of our Argyllshire igneous areas into a series of concentric belts or zones showing an uniformly progressive increase in basicity from centre to margin. Kentallenite, for instance, may occur, as in the Ballachulish area, nearer to the granite than diorite; while, as the Ben-Bhuidhe area again shows, granite may occur in the same zone with kentallenite. Broadly speaking, however, it is true for each eruptive area that the more basic intrusions have invaded the marginal portion, while the more acid material occupies the centre. The phenomenon of the distribution of separate intrusions of a common origin is exactly parallel to that of the distribution of the material of a single intrusion varying in character from centre to margin. The phenomena, too, of the dykes and sills present a general parallelism to that of the more deep-seated masses; and we cannot but regard both as belonging to the same series of events.

From these considerations, and on the petrological grounds already advanced, we do not hesitate to adopt the view that the various related intrusions of the Ben-Bhuidhe and other igneous areas under consideration, owe their origin to differentiation in a common parent-magma. It would hardly, however, be within the scope of the present communication to enter at any length into the speculative physics bearing on the particular type of magmatic differentiation of which they represent the final result. At the same time, it will not be out of place to indicate briefly what we consider may have been the main lines that such a process may possibly have followed.

The phenomena which are illustrated in the Argyllshire eruptive areas would not appear to differ to any great extent from those already well known from other regions, and so admirably described by many American and Continental petrologists, such as Rosenbusch, Brögger, Iddings, G. H. Williams, Weed & Pirsson, and

[1] Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 104.

by Teall, Harker and others, in our own country. We have a variety of separate intrusions, of the same geological age, ranging from basic to acid and forming a closely connected assemblage, or, in other words, a series of rocks from independent magmatic eruptions which show also a continual progression or gradation. In addition to this, we have also described a case of a similar kind of gradation in a single intrusion, in which granite passes marginally into augite-diorite. A progressive series of this latter type has been termed a facies-suit; and we may cite as typical examples of this the shonkinite-laccolites of Square Butte and Yogo Peak, Montana, described by Messrs. Weed & Pirsson. What is true of a facies-suit on a comparatively small scale, is also true of a series of separate intrusions on a larger scale. Owing to the remarkable parallelism in the two phenomena, it is possible that both owe their present petrological characters to a similar kind of magmatic differentiation, which in the one case has taken place within the limits of a single intrusion, and in the other case has been controlled by more deep-seated conditions. In both cases we have to deal with differentiation which has resulted in the production of basic material marginally. To glance briefly at one of the American examples, the Square-Butte laccolite, Messrs. Weed & Pirsson[1] conclude that after the intrusion, differentiation took place in the liquid mass, the iron-, magnesia-, and lime-molecules being greatly concentrated in a broad exterior zone, leaving an inner kernel of material richer in alumina, alkalis, and silica. This latter crystallized into a sodalite-syenite, while the outer mass formed the basic rock to which the name shonkinite has been given. The mass—shonkinite + soda-syenite—forms a geological unit. Differentiation, according to the above-mentioned authors, took place *in situ*, and was regulated by the diffusion of the basic oxides to the outer cooling surface. This idea is apparently confirmed by Prof. Brögger's conclusions with regard to the eruptive rocks of Gran in Norway[2] and in other areas, and by Mr. Harker's studies of the Carrock-Fell gabbro.[3] It seems not unreasonable therefore to conclude that a similar type of differentiation is illustrated in the Ben-Bhuidhe area. Thus, in the case of the single intrusion on Beinn Chas, showing basic material developed marginally to more acid, we may suppose that a similar kind of differentiation took place in the magma subsequently to intrusion, resulting in the production of more basic material surrounding a more acid core. That the differentiation in the case of the various Ben-Bhuidhe intrusions, ranging from granite to kentallenite, was also of a marginal character, the distribution of the different rock-masses sufficiently shows. On the other hand, it must have taken place in the parent-magma of these intrusions under much more deep-seated conditions, our knowledge of which is necessarily of a strictly limited nature. But whatever may have been the determining factor in the process,

[1] Bull. Geol. Soc. Am. vol. vi (1895) p. 422.
[2] Quart. Journ. Geol. Soc. vol. l (1894) p. 15.
[3] *Ibid.* p. 311 & vol. li (1895) p. 125.

whether diffusion or some other cause, the parent-magma evidently became differentiated into basic and acid portions, the former, judging from the relative positions of the resulting extrusions, being marginal with regard to the latter. Such differentiation may be said to be of a 'complementary' character, the extremes of the resulting series representing 'complementary' rocks, whose average composition would represent approximately that of the original undifferentiated magma.

Among the intrusions of the dyke or sill-phase we would suggest that the more acid and more basic series thus stand as 'complementary' groups, with transitional types. Prof. Brögger has especially drawn attention to such a relationship among the camptonite- and bostonite-intrusions associated with the olivine-gabbro-diabases of Gran.

It is probable that the original magma which underwent differentiation in our Ben-Bhuidhe area was one of more or less intermediate character, approximating in composition to tonalite, and that a process of complementary differentiation in such a magma produced the augite-diorites and kentallenites on the one hand, and the hornblende- and biotite-granites on the other. The constant association of a generally similar assemblage of rocks in each Argyllshire area is strongly in favour of the view of their origin in each case by differentiation in a common magma. And, moreover, the grouping of the basic rocks in each area about the more acid, as about a common centre, supports the idea of a similar type of differentiation having taken place, along parallel lines, in the respective reservoirs which constituted the source of supply for each eruptive centre.

VI. Summary.

We may now briefly summarize the main conclusions at which we have arrived in the foregoing pages. Under the term kentallenite we have described a peculiar group of basic rocks, which may be defined as consisting essentially of olivine and augite, with smaller amounts of orthoclase, plagioclase, and biotite, while apatite and magnetite are accessory. The most striking feature of the rocks is the peculiar association of alkali-felspar with olivine and augite. The group is related to the shonkinite of Square Butte and Yogo Peak in Montana, and to the olivine-monzonites (Brögger) of Scandinavia.

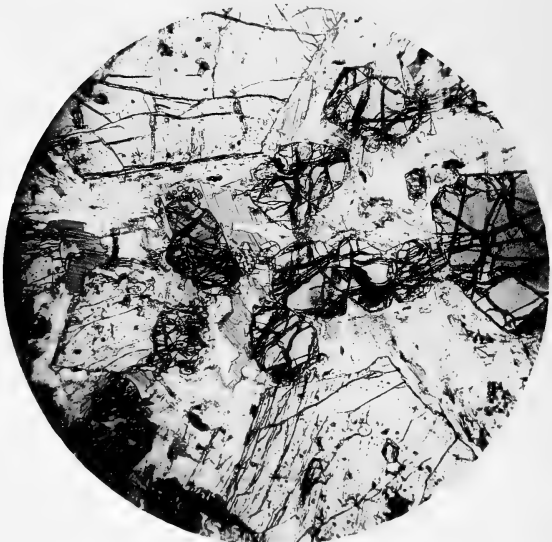
Kentallenites are distributed over a large portion of Argyllshire, and appear to be associated with four more or less distinct centres of eruptive activity, each of which is characterized by important intrusions of various granites and diorites, and, in most cases, also by a profusion of dykes and sills of lamprophyres, porphyrites, etc. The kentallenite-group represents the most basic intrusion of each of the areas where it occurs, and it is found in the more outlying or marginal portions of each of those areas respectively.

We have pointed out, chiefly from evidence collected in the Ben-Bhuidhe area, that close relationships exist between these kentallenites and certain augite-diorites occurring in the same district, and

that these latter may be connected by transitional types with acid biotite-granites. The augite-diorites, allied to kentallenite, occur, not only as separate intrusions, but also as the marginal modification of a granite-intrusion. Similar relationships are found to hold good in the other Argyllshire areas where kentallenite is found, namely that of Ben Cruachan, that of Loch Avich and Kilmelfort, and that of Ballachulish. Moreover, kentallenite proves to be not only thus connected with the intrusions of diorite and granite, but also to have close relationships to the numerous lamprophyre-intrusions which are a characteristic feature of that portion of the Ben-Bhuidhe area which has been invaded by the more basic plutonic masses. Among these lamprophyres we have described certain basic types, rich in pyroxene, both from the Ben-Bhuidhe and Ben-Cruachan areas, and have indicated the relationships between these and the augite-diorites, allied to kentallenite. The basic lamprophyres again are shown to be connected with the camptonites and hornblende-porphyrites by a series of intermediate varieties. We thus may conclude that the Ben-Bhuidhe complex of intrusive rocks constitutes a closely related and associated assemblage, ranging, in the plutonic phase, from granite to kentallenite, and, in the dyke- or sill-phase, from orthoclase-porphyry and porphyrite to augite-lamprophyre; and further, that this assemblage has been derived by a process of differentiation from one parent-magma. The order of intrusion in this area has been in the main in the order of increasing acidity.

Not only have we a series of rocks consisting of separate intrusions of varied rock-types owning a common origin, but also a facies-suit, constituting one of these intrusions, and showing a progressive increase in basicity from centre to margin. In the one case (facies-suit) differentiation has taken place subsequently to intrusion, and in the former case under more deep-seated conditions, previously to intrusion. In each case we suppose that there has been a concentration of the more basic oxides in the more marginal, and therefore cooler portions of the magma, and that this process has resulted finally, in the case of our series of separate intrusions, in the outer portion of the magma becoming richer in basic oxides, and so capable of erupting a variety of basic rocks into the more marginal portion of the area, while the central part has been invaded by more acid rocks. In the facies-suit differentiation took place *in situ*, and was followed by consolidation of the mass, so as to produce an intrusion with an acid core passing gradually into a basic marginal portion. The magma, from which the various rock-types were derived, was probably originally of more or less intermediate composition, differentiation in which probably resulted in the production of 'complementary' rocks, constituting the extremes of the rock series. Furthermore, the close parallelism between the intrusive phenomena of the other Argyllshire eruptive areas and those of Ben Bhuidhe, renders it extremely probable that in each area a similar type of differentiation took place along parallel lines; and from the fact that in each case more or less similar rock-types have been

1.



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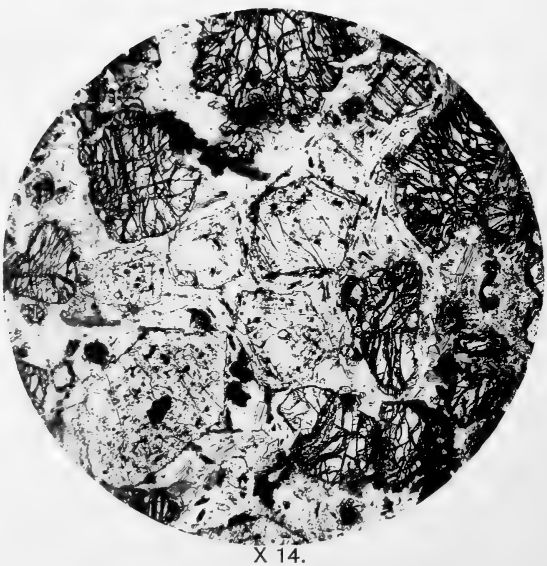
2.

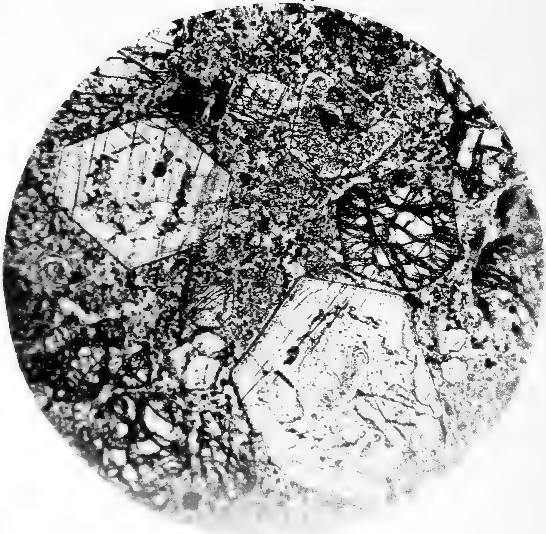


X 14.

Kentallenites from Argyllshire.

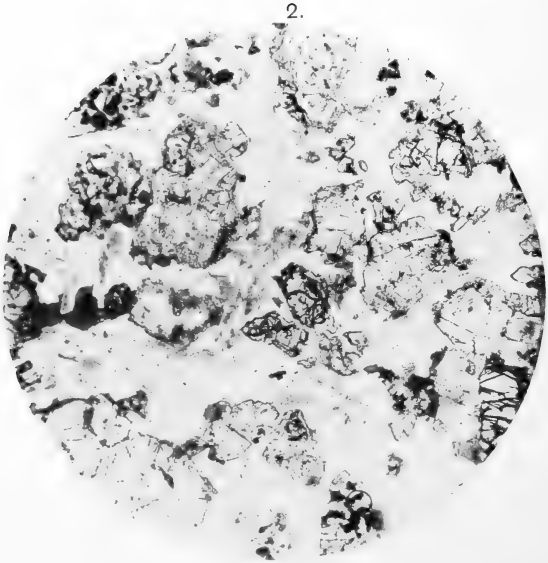
Photo-micro. H. Kynaston.

1.



X 13½.

2.

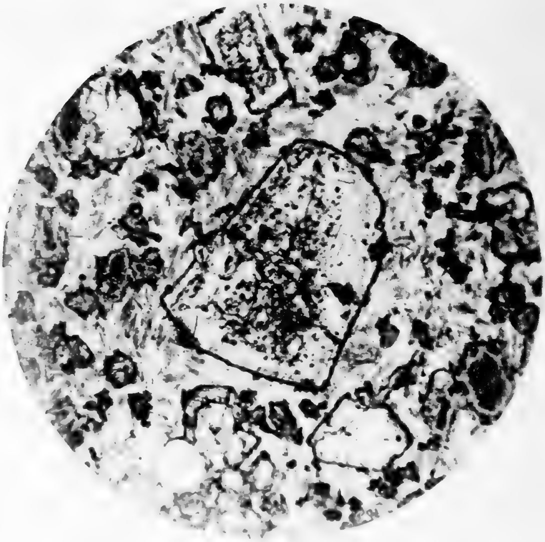


X 13½.

Kentallenites from Argyllshire.

Photo-micro. H. Kynaston.

1.



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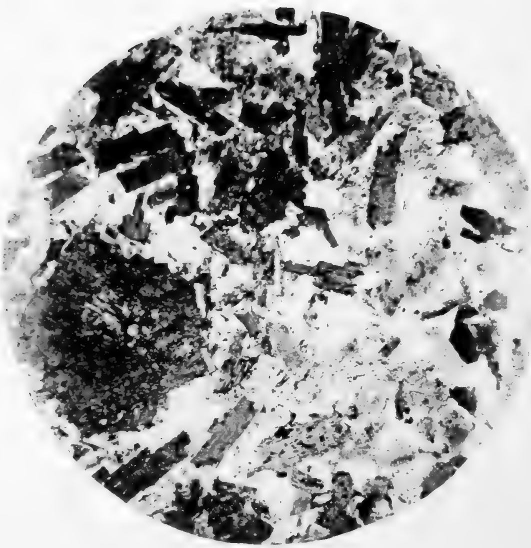


X 13½.

Augite-Diorite and Quartz-Diorite from Argyllshire.

Photo-micro. H. Kynaston.

produced, we may conclude that the underlying magmas resembled one another more or less closely in composition. These somewhat similar sources of supply doubtless represent local magmas, derived from a more general magma-basin.

In conclusion, we would express our cordial thanks to Mr. J. J. H. Teall, F.R.S., for valuable hints and suggestions in the microscopical examination of many of our rock-types.

EXPLANATION OF PLATES XXIX–XXXI.

Plate XXIX.

Fig. 1. Kentallenite from Kentallen Quarry, near Ballachulish (Argyll): type-rock. (See p. 534.) *Cf.* Teall, 'Brit. Petrogr.' pl. xvi, fig. 1. The slide shows olivine-grains, with anastomosing cracks filled with magnetite; idiomorphic augite; ragged plates of biotite, which are moulded on the olivine, augite, and plagioclase. The clear portion consists of more or less idiomorphic plagioclase and interstitial orthoclase in approximately equal proportion. ×14.

2. Kentallenite from Glen Orchy (Argyll), from a portion of the mass rich in basic minerals. The slide shows much olivine, marked by a network of cracks, and augite in smaller quantity. Biotite and felspar appear to play the part of groundmass to the olivine and augite. There is a decidedly smaller proportion of orthoclase in this rock than in the Kentallen type. ×14. (See p. 534.)

Plate XXX.

Fig. 1. Phase of the Glen-Orchy mass, with structure resembling the porphyritic. Idiomorphic augite and more or less idiomorphic olivine are conspicuous in a groundmass of small biotite-flakes and felspar. Neighbouring flakes are often seen to be in optical continuity, and to be moulded upon the plagioclase. ×13½. (See p. 534.)

2. Kentallenite from Allt-an-Sithein, Ben-Bhuidhe area. This shows more orthoclase and decidedly less olivine than the three preceding figures. The idiomorphism of the augite is seen to be far less perfect than in the more basic types from Kentallen, etc. There is not so much biotite as in the Brannie-Burn rock. The orthoclase occurs in micropœcilitic patches, in which the plagioclase-laths are embedded without orientation. This rock contains hypersthene, in more or less corroded grains, in addition to the augite. ×13½. (See p. 535.)

Plate XXXI.

Fig. 1. Marginal portion of intrusive mass on Beinn Chas, Ben-Bhuidhe area. ×13½. (See p. 544.) Augite is abundant showing more or less idiomorphism, and often a narrow alteration-border of green hornblende. Small biotite-flakes and more or less idiomorphic plagioclase may also be seen. A very small proportion of alkali-felspar may possibly be present. The rock resembles some of the more basic lamprophyres of the district, as well as the augite-diorite, occurring north-west of Clachan Hill, related to kentallenite.

2. Quartz-diorite of the tonalite-type, part of the same intrusion as the preceding, but from a more central portion. ×13½. (See p. 545.) The slide shows green hornblende, biotite, more or less idiomorphic plagioclase (turbid from alteration), orthoclase, and interstitial quartz. This type passes in the central portion of the mass, by the loss of hornblende and the increase in proportion of felspar and quartz, into a biotite-granite (of the Ben-Bhuidhe type).

Discussion.

The President said that he had a personal interest in this type of rock. He had described a specimen from Kentallen in 'British Petrography' as a plagioclase-augite-olivine-mica rock. Later on he had re-examined the rock for the Geological Survey, and had recognized orthoclase as an important constituent of certain varieties. He had felt that the rock was peculiar, but in the absence of full knowledge as to its field-relations had hesitated to invent a new name, and so had termed it olivine-monzonite. The Authors had worked out the field-relations of the rock, and had examined many varieties. He thought that they were justified in proposing a new name. Apart from general appearance and mode of weathering, both of which were characteristic, the distinguishing feature was the abundance of olivine and augite in association with varying proportions of orthoclase and plagioclase. If Prof. Brögger's definition of monzonite were accepted, it could not be applied to this rock. Some varieties were rich in orthoclase. This indicated affinities with olivine-minettes and with some of the Permian traps of the Exeter district, in which Prof. Watts had detected olivine and orthoclase. Basic rocks rich in potash also had chemical affinities with leucite-bearing lavas, and he felt that if leucite were ever found in England it would be in the Exeter district.

Sir Archibald Geikie said that he wished to express the gratification with which he welcomed so careful a paper by two members of his Survey staff. The field-relations of a remarkable group of rocks had been worked out with great skill, and a fresh example had been studied and illustrated of the connexion of a granite-core with peripheral basic extrusions. Though we were still far from having solved the mysteries of 'differentiation,' there could be no doubt that their solution would be most satisfactorily and speedily reached by such a research as that which had been brought forward by the Authors, combining, as it did, an ample collection of field-evidence with a minute study of the internal composition and structure of the rocks.

Prof. Sollas commented on the interesting nature of the rock which had been so excellently described and illustrated. The collection of more basic material in the cooler portions of a magma offered a tempting basis for a consistent hypothesis of differentiation; but it seemed still doubtful whether this hypothesis deserved the importance that it had acquired. Marginal changes in dykes might be produced in more ways than one, and the appearance of quartz in olivine-bearing rocks was suggestive of the action of water. Terms which could only be spoken of as barbarous—such as facies-suit—by no means conduced to clearness of expression, and it was to be hoped would never find a home in the English tongue; nor did it appear that anything was gained by framing a new substantive name from Kentallen, which might with greater advantage have been used as an adjectival qualification.

Prof. Watts and Mr. Prior also spoke.

29. Mechanically-formed Limestones from Junagarh (Kathiawar), *and* other Localities. By John William Evans, D.Sc., LL.B., F.G.S., formerly State Geologist to the Junagarh State. (Read June 6th, 1900.)

Contents.

I. The Original Structures of Mechanically-formed Calcareous Rocks—Subaqueous, Littoral, and Æolian.

We are apt to think of the calcareous rocks as being laid down differently from other sedimentary strata. It is recognized at once that the deposition of the latter involves the mechanical forces of rivers, currents, waves, or winds; but the former—when they are not the result of chemical precipitation—are often spoken of as if they represented merely the undisturbed accumulation of calcareous material, which either remains where the organism, of which it formed part, ceased to live, or sinks by its own weight at once to the sea-bottom.

This distinction is, however, as every one would admit, only very partially valid. All the structures characteristic of the sedimentation of arenaceous beds are exhibited, on occasion, by calcareous rocks; though when these are formed in the sea, the phenomena are restricted and modified by the fact that carbonate of lime is soluble to a very large extent in water containing carbonic anhydride.[1]

As a general rule, the water of rivers, lakes, and seas is not completely saturated with carbonate of lime, and therefore acts as a solvent of that substance. A small calcareous particle—whether it is derived from the erosion of a limestone; or is the result of the comminution of shells, corals, and other organic remains; or represents the test of a minute organism—will not remain long suspended in water which is still capable of taking up carbonate of lime, before it disappears into solution. Fine-grained calcareous material will consequently, under ordinary circumstances, be deposited only when there is so little current that the particles speedily sink to the bottom, where the water is saturated with lime from the calcareous

[1] Solution and recrystallization subsequent to the formation of the rock also tend to obliterate these structures.

deposit that has already accumulated. Current-phenomena such as false-bedding cannot, therefore, be expected to occur in calcareous rocks formed in water under normal conditions.

But although the water of seas and lakes is in general imperfectly saturated with carbonate of lime, this is by no means always the case. Under certain circumstances—especially in hot countries and in the immediate vicinity of coral-reefs and other calcareous rocks or deposits—the water becomes so loaded with calcareous material that it will, instead of dissolving fine calcareous particles, cover them with an envelope of carbonate of lime. If the water is not in motion, adjoining particles will be cemented together into a solid mass; but if there is sufficient current or wave-motion to prevent this, a free rounded grain consisting of a calcareous envelope surrounding the original object will be the result. If the saturation and movement of the water continue, the process will be again and again repeated till the grain is too large to be disturbed by the motion of the water, and an oolite-grain will be formed.[1] Nor is there any necessity that the nucleus should be calcareous: a fragment of quartz, a crystal of hornblende, a siliceous sponge-spicule, or perhaps even a particle of organic matter, will serve the same purpose.[2] It will be seen at once that the conditions under which oolite is formed—rapid movement and the saturation of the water—are exactly those which we might expect to favour the development of current-phenomena in fine-grained calcareous rocks, and we do in fact find false-bedding commonly occurring in the typical oolites of the Jurassic period.[3]

Although calcareous rock formed by the mechanical action of moving water presents some abnormalities as compared with arenaceous deposits, the subaerial calcareous beds accumulated by the transporting power of the wind have the closest resemblance in structure to æolian deposits formed of other materials. The usual sources of the grains of a wind-formed calcareous rock are the littoral deposits on the sea-shore, though upraised subaqueous deposits and earlier æolian accumulations may contribute their share. Calcareous particles of marine origin—foraminifera and other minute organisms, small fragments of shell or coral, and

[1] See [49] p. 106, [25] p. 483, [46] pp. 14, 19 & [52] p. 102. It does not fall within the province of this paper to discuss the action of algæ in promoting the formation of oolite-grains. Nor has it yet been proved that their presence is a necessary condition; but it is possible that in some cases they cause the formation of oolite, even in unsaturated water. [Numbers in brackets throughout this paper refer to the Bibliography, § X, p. 581.]

[2] Darwin described the deposition of carbonate of lime at Ascension on a large rock-surface when the sea-water was saturated with carbonate of lime (in the hot season), and its disappearance by solution or abrasion when (in the cold season) the water was again in an unsaturated condition: see [14] p. 50; [27] A p. 57 & B pp. 198–99. He also recorded at St. Helena the covering of pebbles with a calcareous pellicle by the action of percolating water, and apparently the formation of oolite in the same manner, [14] pp. 86–89; [27] A pp. 88–101 & B pp. 222–24.

[3] [45] p. 282. We must not, however, lose sight of the possibility that some of these Jurassic oolites may be of æolian origin: see p. 579.

oolite-grains, which from their size and shape are susceptible of movement by the wind—are in this manner carried many miles inland and often high above the level of the sea, where they form stratified deposits which at first sight appear, from their structure and the organisms whence the grains are derived, to be marine deposits. On further examination, however, there is seen to be a remarkable absence of marine organic remains larger than those which could be easily transported by the wind, and if there are any large fossils they are found to be terrestrial forms.

Littoral calcareous deposits occupy an intermediate position, both with respect to the materials of which they are composed and the structures which they exhibit (see p. 574).

In the neighbourhood of the coast-line of most of the countries bordering on the Arabian Sea are a number of granular calcareous deposits which sometimes show well-defined false-bedding. They are characterized by the presence of foraminifera, which play an important, though scarcely a predominant, part in their composition, and were called the Miliolitic formation or Miliolite by H. J. Carter, who first examined them microscopically, on account of the prevalence of forms belonging to the genus *Miliola*: see [3] pp. 166-67, 169–73; [4] A p. 34 & B p. 568; [5] A p. 314 & B p. 757.

In giving a short account of these beds, and discussing their mode of origin and the points whereby they illustrate the principles outlined in these introductory remarks, I have taken the limestone of Junagarh in Kathiawar as the type. I had an opportunity of examining it some years ago, when engaged in geological and prospecting work in the Junagarh State. It has not hitherto been described, but from the thickness to which it is developed, and the interest of its structure and contents, it seems not unworthy of attention.

The micro-organic remains have been carefully worked out by Mr. Frederick Chapman, whose results appear in the paper following this.

II. The Junagarh Limestone. (Map, fig. 1, p. 562.)

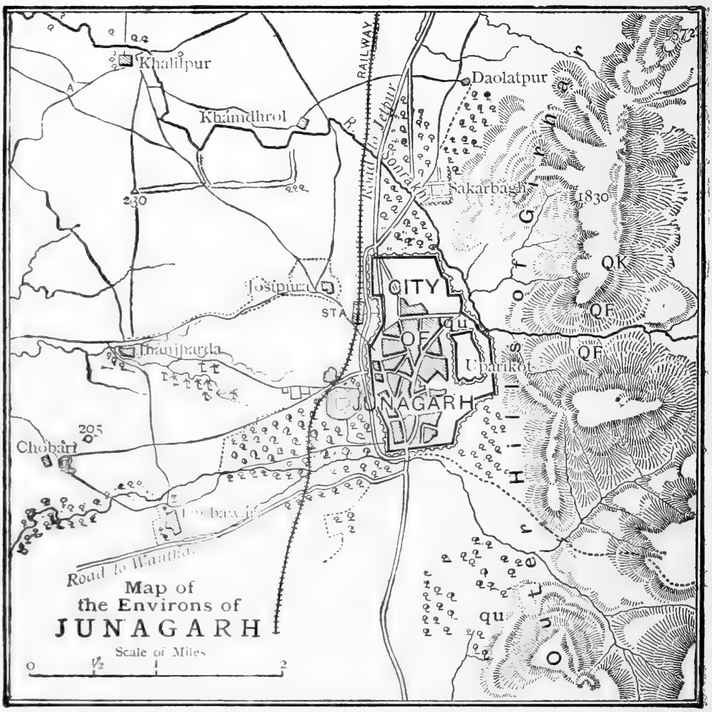
The city of Junagarh, the capital of the Kathiawar State of the same name, is situate on an extensive hill formed of a granular calcareous rock, known as the Junagarh Stone or Limestone, which rests on the flat denuded surface of the Deccan Trap immediately west of the isolated mountain-group known as Girnar, and at a distance of about 30 miles from the sea.

The citadel or Uparikot[1] occupies the summit, which rises to a height of 488 feet above sea-level. On the north and east there is a steep descent to the River Sonrákhi, which emerges from Girnar by a narrow gorge opposite the Uparikot and passes north of the city; on the west the ground slopes more gently. In the

[1] This is, I believe, the correct spelling, but the *i* is scarcely pronounced.

course of a mile, however, it falls to a level of scarcely more than 200 feet above the sea. On this slope the main portion of the city is built. Comparatively high ground extends for some distance south of the city, connecting on the south-east with the lower slopes of the outer hills of Girnar, and appears to be formed throughout of the same limestone. It is impossible to define the limits of the formation under the cultivated land near Junagarh. I found one exposure (at the point marked A on the map, fig. 1)

Fig. 1.



qu = Quarries. A = Exposure of limestone near Khalilpur.
QK = Quartz-keratophyre. QF = Micropegmatitic quartz-felsite.

about $3\frac{1}{4}$ miles north-west of the city, and about $\frac{1}{2}$ mile west-south-west of the village of Khalilpur, on the Sonrákhi. This is at an elevation but little exceeding 150 feet above sea-level.

In some places the Sonrákhi has cut down to the Deccan Trap-rocks below the limestone, but the junction is obscured by calcareous tufa, derived partly from the latter and partly from the decomposition of igneous rocks in the area drained by the river. Near the Uparikot, the surface of the trap can scarcely be much

more than 250 feet above sea-level, so that the maximum vertical thickness of the Junagarh Limestone probably exceeds 200 feet.

The larger structure of the rock is well seen at the Uparikot in two deep wells, which can be descended by spiral steps cut in the rock; but a more extensive section is available in the quarries on the northern side. The limestone is divided nearly horizontally by planes 3 or 4 feet apart, which mark decided breaks in the deposition. Between these the lamination is very oblique and is cut off abruptly, both above and below, by the major divisional planes. On either side of such a plane the inclination of the lamellation is usually different, and the direction may either remain the same, or be varied or reversed. The usual direction of the dip of the laminæ appears to be to the east. The inclination may be anything up to about 30° with the horizontal, and may vary from point to point of the same division of the rock; but on the whole the structure is fairly regular, in fact rather more regular than in most false-bedded strata.[1] Similar structure is seen, though not so well, in the quarries south-east of the city at the foot of the Girnar Hills.

I carefully enquired of the quarrymen whether they ever met with anything in the nature of a fossil, and was answered in the negative; nor was I able to find any object enclosed in the rock larger than the grains of which it is composed.[2]

In hand-specimens[3] the limestone has a remarkable resemblance to oolite, as the grains are mostly well-rounded and just visible to the eye. Rocks of similar character from other parts of Kathiawar were, in fact, described as oolites by the earliest observers. As will appear from Mr. Chapman's paper, on microscopical examination these rocks are seen to be mainly formed of organic calcareous particles derived from shallow-water organisms of recent types. Each particle is ordinarily surrounded by an envelope of deposited carbonate of lime, the whole being bound together by a later cement of the same material. Oolitic grains occur, but do not as a rule show the structure well in thin sections.

Interspersed through the mass are minute fragments derived from the igneous rocks of the neighbourhood. They are, like the calcareous constituents, cemented into the rock by calcite, but are rarely surrounded like them by a true pellicle of calcium carbonate.[4] They seldom exceed 1 millimetre in diameter, and form only a small proportion of the entire deposit. I have studied them both

[1] The section from the Forest Marble of Somerset figured by De La Beche [49] p. 536, and that of desert-sand in Prof. Walther's 'Denudation in der Wüste' [29] p. 519, are very similar in character, though not quite so regular.

[2] An occasional particle of igneous rock rather larger than the calcareous grains was visible in places.

[3] Specimens, microscope-sections, and residues (after treatment with acid) of these and other similar Kathiawar rocks have been deposited at the Museum of Practical Geology, Jermyn Street.

[4] The calcite-crystals of the cement are usually small in the immediate neighbourhood of the inclusions, and at first sight sometimes have the appearance of an envelope round them.

in thin sections of the rock, and in the residue obtained on treatment with dilute acid. Besides the igneous particles, the residue contained yellowish casts of the interior of the foraminifera and other organisms [1] and a little ferruginous dust.

The limestone (I, 283 Q) from the quarries south-east of the city contains about 6·5 or 7 per cent. of material insoluble in dilute acid. A large proportion of this consists of casts of organisms. The inorganic portion of the residue includes quartz usually angular, occasionally rounded, rarely idiomorphic; a basic triclinic felspar, which from its optical properties in thin sections and cleavage-plates appears to be labradorite or bytownite, though a few flakes of oligoclase occur; rounded augite; and greenish decomposition-products. All these, with the possible exception of the quartz, appear to be derived from the basic igneous rocks which form the main mass of the outer hills of Girnar. The angular quartz may either represent secondary quartz from the same rocks, or may be derived from the quartz-bearing rocks which are intrusive in them. It is, however, improbable that the latter contribute much, as their quartz occurs usually in idiomorphic crystals or lenticular blebs. The rounded quartz probably comes from a distance. A thin section (II) of the limestone in the neighbourhood of the Uparikot shows material of igneous origin, similar in character though perhaps rather less in amount. A specimen (III, 165 A) from the exposure near Khalilpur, mentioned on p. 562, contains about $12\frac{1}{2}$ per cent. of residue insoluble in dilute acid.[2] The particles of igneous origin obtained were found to be, in the first place, plagioclase and rounded augite similar to those in specimen I, as well as minute fragments of basaltic matrix; all of which were probably derived from the basic rocks already referred to, though some may have come from the gabbro higher up the course of the river; secondly, idiomorphic quartz and a triclinic felspar, whose optical properties place it near oligoclase, which seems to be derived from a quartz-keratophyre intrusive into the basic rocks, exposures of which are now found on the northern side of the Sonrákhi gorge. Small particles apparently forming part of the groundmass of the same rock also occurred. A fair amount of rounded and polished quartz as well as angular quartz were likewise found in the residue.

When first quarried the limestone is rather soft, but it soon hardens on exposure. It is very durable, and in great request for building. For this purpose it is cut into flat rectangular blocks, the larger faces of which follow the planes of lamination. It has been carved *in situ* into various figures and excavated to form

[1] The material forming similar casts in other 'miliolites' was considered by Carter [3] p. 170, and [4] A p. 34, B p. 568, to be identical with the molluskite of Mantell [47, 48, & 50]; but see [5] A p. 313 & B p. 756, where he describes it as yellow ochre.

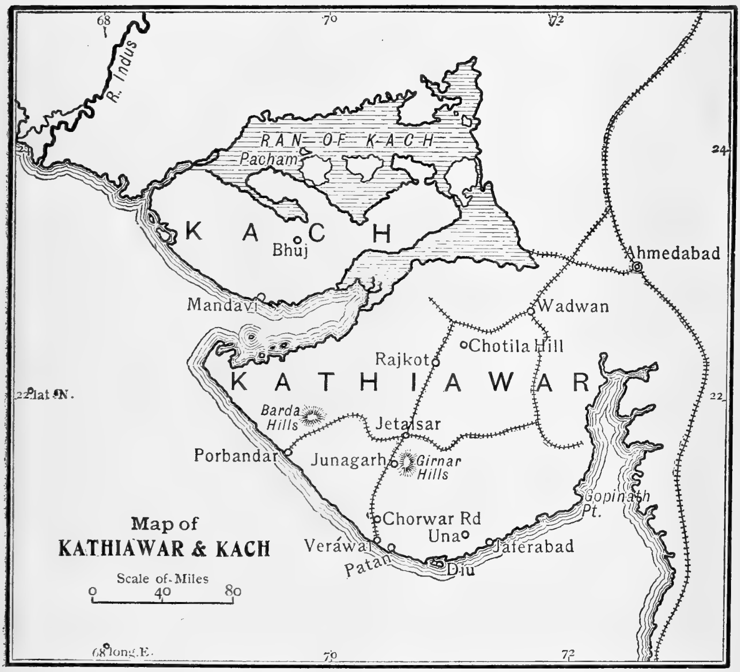
[2] In one determination as much as 25 per cent. was obtained; but the material treated appears to have included a broken-up felspar-crystal, which constituted the greater part of the undissolved residue.

subterranean cave-temples, both in the Uparikot itself and in the lower ground on the north. This is supposed to have been mainly the work of the Buddhists, and, in that case, it must have been executed at least a thousand years ago: probably it is even older than this. Some portions are still in a state of good preservation.

III. Other Kathiawar Rocks of Similar Character.

I was able to examine a somewhat similar limestone, of no very great thickness, near Chorwar Road Station, on the Junagarh & Veráwal Railway, about 6 miles from the sea-shore. It rests on the Tertiary beds that fringe the southern coast of Kathiawar.

Fig. 2.



Specimens IV & V, 279 M & O, from this locality gave respectively 3 and nearly 6 per cent. of insoluble residue. Examination of thin sections and residue showed grains of quartz, sometimes rounded and sometimes angular, and occasional flakes of plagioclase, in addition to a little ferruginous material and casts of organisms. I saw the same rock, with similar stratigraphical relations, extensively developed near Una farther east, at about the same distance from the sea.

A deposit resembling in many respects the Junagarh Limestone

is found along the western base of the Bárda Hills, about 9 miles north-east of Porbandar. The rock is exported from Porbandar for building-purposes under the name of Porbandar Stone. Specimens were examined by H. J. Carter, and described by him in a paper read before the Bombay Branch of the Royal Asiatic Society in 1848 [3]. He assumed, without question, that it was a subaqueous deposit; see [5] A p. 313 & B p. 756.

Mr. Fedden, of the Geological Survey of India, states, in his memoir on the geology of Kathiawar [9] p. 135, that the Porbandar Stone is very thick and

'occurs in three parallel ridges or ledges rising one above the other; it is white-coloured, and very obliquely laminated at an angle of about 22°, varying in different quarries.'

By the kindness of Mr. Chapman, I have had the opportunity of examining a specimen (VI) of this rock. On treatment with acid, less than 2 per cent. of insoluble material remains. This consists, in addition to casts of small organisms, of a little angular quartz and occasional flakes of felspar. In a thin section of the rock no extraneous matter, except a few grains of quartz, was visible. As will be seen from Mr. Chapman's paper, oolitic grains have been found among the calcareous constituents of the rock.

Mr. Fedden found somewhat similar deposits in other parts of Kathiawar. He states [9] pp. 126–28 that the 'miliolite'

'forms the bluffs and cliffs on the south-eastern coast and extends some way inland sheeting the surface of the country. . . . In the eastern part of the alluvial area it is seen only near the coast, while to the westward the whole country is encrusted with the rock.' . . . 'The farther it occurs from the coast the purer is the limestone, while that along the sea-board is not infrequently mixed with much sand.'

At Gopinath and Jaferabad it is interstratified with light calcareous sandstone. At the former locality some of the beds are 'earthy and rubbly.' He records, on manuscript authority, that Mr. Theobald in 1858 noted the occurrence in the rubbly beds of two species of *Bulimus*, two of *Helix*, and one of *Cyclotus*. At Motra Kotra 'grey softish' calcareous sandstone occurs between two beds of 'miliolite.' The sandstone,

'though unbedded, is laminated obliquely in various directions after the manner of blown sand, and it seems probable that much of the grey slightly coherent sandstone consisted of blown sand in the form of dunes that became submerged.'

At Veráwal the 'miliolite' passes laterally into an open, porous, sandy rock, made up very largely of organic fragments and minute organisms, resembling a raised beach in the vicinity.

The 'miliolite' in the interior is stated to occur

'capriciously in the gorges of the hills or as patches on their sides like remnants of a snowdrift.'

On Chotila Hill it forms a fringe round the truncated top, at a height of 1173 feet above sea-level.

Like Dr. Carter, Mr. Fedden had no doubt that the 'miliolite' was throughout a marine formation; see [9] p. 127.

IV. Deposits in Kach. (Map, fig. 2, p. 565.)

Deposits of a similar character are also found in Kach (also spelt Kutch or Cutch), where they were described by Mr. A. B. Wynne, of the Geological Survey of India [8], under the name of 'concrete,' as occurring both on low ground at the foot of the hills bordering on the Ran [1] as well as high in the glens. It is sometimes interstratified with 'coarse soft calcareous sands' (*op. cit.* p. 93). Along the coast at two or three places west of Mandavi, a littoral 'concrete,' formed of the shore-sand consolidated and cemented by carbonate of lime, is worked between tides (*ibid.*). A small patch of 'subrecent littoral concrete' full of marine shells is stated to occur on the northern shore of Pacham (or Putchum) at a height of nearly 20 feet above the Ran (*op. cit.* pp. 27 & 103).

Subsequently some of the Kach deposits were examined in greater detail by Prof. J. F. Blake [10], who states (p. 229) that they

> 'consist of fine particles very slightly agglutinated so that a blow of the hammer shatters them to dust. Some southern varieties are tougher, and are used for building. . . . They are for the most part obliquely laminated, and in this case the slope of the laminæ in the part of the deposit nearest the solid rock is in the direction of that rock. In composition the majority are mostly white sand cemented with calcareous matter. In the more southerly exposures there are calcareous particles also, which are completely rounded, and on examination appear to be organic fragments. All the localities may be described as spots where a wind coming from the west or south would be stopped by an obstacle, or where a shelter-spot exists on a long scarp.'

He urges that these strata cannot be marine, as the only large organic remains are land-shells (*Buliminus*), and that rocks laid down under water never have this loose porous structure.

It will be noticed that the Kach deposits described by Prof. Blake differ considerably from the Junagarh Limestone and Porbandar Stone; they are much less pure, containing in fact a large proportion of arenaceous material, and are apparently of a rather more friable nature.[2]

V. Similar Beds on the South-eastern Coast of Arabia and the Islands in the Persian Gulf. (Map, fig. 3, p. 568.)

It is on the south-eastern seaboard of Arabia that limestones of the Junagarh or 'miliolite'-type are most extensively developed. They have been described in some detail by H. J. Carter [4].[3] They usually overlie the Nummulitic Limestone, but sometimes rest

[1] Also spelt Runn: a low sandy waste, flooded in the rainy season, and formerly covered by the sea.

[2] The same characters will probably be also found in the deposits described by Mr. Fedden as occurring in the gorges of the hills of Western Kathiawar. I have never examined them, but cannot believe that the rule laid down by him, that the beds in the interior are purer than those immediately adjoining the sea-shore, applies in all cases to deposits found at a considerable distance from the coast; see p. 573 of this paper.

[3] See also [3] & [5].

directly upon the granite. Near Ras Abu Ashrin, see [4] A pp. 33–34 & B pp. 566–68, is

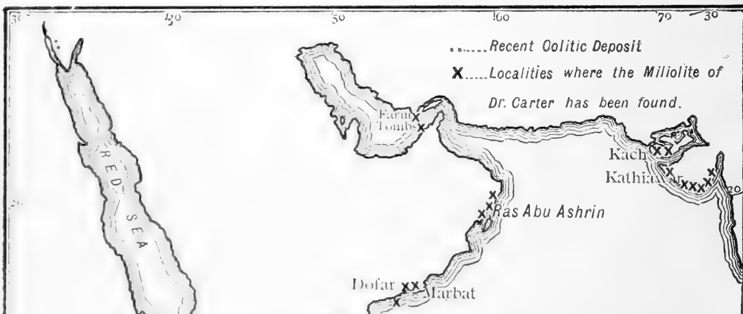
'a tract of white dome-shaped sand-hills from 100 to 200 feet above the level of the sea. These extend inland as far as the eye can reach, and are scarped upon the sea'.[1]

The formation consists of a 'sandy grained rock' formed of

'calcareous particles with a small quantity of hyaline quartz and dark specks, probably hornblende, from the igneous rocks. . . . There is hardly a fossil larger than the grains of which it is composed to be seen in any part of it; it is more or less stratified and, though loose in structure, sufficiently compact to form a good building-stone. . . . It is so loose on the surface that the upper and exposed part has become disintegrated for some depth. . . . In some parts the sand is so subtle that it yields to the lightest weight, while in others it is so caked that it will bear that of a man.'

He compares these calcareous sand-hills to pictures that he has seen of drift-mounds of snow in the Arctic regions.[2] The calcareous particles are stated to consist of the remains of minute foraminifera.

Fig. 3.



The 'miliolite'-deposits here and at many other points on this coast resemble the Junagarh Limestone and Porbandar Stone, and similar deposits in Kathiawar and Kach, in the striking absence of organic remains larger than the granules of which the rock is made up. But this is by no means the case everywhere on the south-eastern coast of Arabia, as the following extracts will show:—

'Capping the plain of Marbat, the highest part of which . . . is about 30 feet above the level of the sea, is a granular deposit composed chiefly of particles of carbonate of lime with which are mixed more or less grains of quartz and hornblende from the igneous rocks on which it reposes. It is about a yard in

[1] The thickness is unknown; the cliffs, which they form, do not exceed 100 feet in height.

[2] He suggests that these may be the winding sands mentioned in the Korân, in which the tribe of Ad is said to have perished.

thickness, and extends in all directions over the plain to within a mile of the sea. It contains a great number of organic remains, consisting chiefly of casts of small bivalves. . . . It fills the inland extremities and crevices of the fissures which . . . extend through this plain to the sea, and there contain very large perfect shells; and adherent to the side of the group of granite-hills at the bottom of the bay is a large mass of it, the upper part of which is 30 feet above the level of the sea. Here it presents a vast quantity of corals with large shells of *Hippopus*, *Ostrea*, etc. All these shells have lost their animal matter, and are more or less friable and pulverulent. This formation in its more subtle material closely corresponds with the miliolitic deposit of Ras Abu Ashrin, and when we have proceeded a little onwards from the igneous rocks, we shall find its composition and appearance almost identical with it': [4] A p. 57 & B p. 590.

Over the plain of Dofar

'is spread a continuation of the miliolite we have seen capping the plain at Marbat . . . but it is more uniform in its composition and more free from dark patches of the igneous rocks. Hence it closely resembles the "miliolite" at Ras Abu Ashrin': [4] A p. 61 & B p. 595.

Against the upper part of the limestone-cliff, in front of the western end of the same plain,

'rests the miliolitic deposit of Dofar, 6 or 8 feet above high water, and filling many holes . . . made by lithodomous animals, and containing oysters of the same kind as those of a bed close by': [4] A p. 62 & B p. 596.

Similar occurrences are noted in other localities along the coast; but in no case are shells reported at a greater height than 40 feet, or borings higher than 30 feet above sea-level, though the deposit in several places reaches a height of 100 feet, and at Makalla Carter believed, on the evidence of fallen blocks, that it existed at a height of 1300 feet above the sea; see [4] A p. 82 & B p. 615.

He subsequently [6, 7] described the occurrence of 'miliolite' in several localities on the Persian Gulf. In the islands known as the Great and Little Tombs and Farur,[1] west of Kishm at the eastern end of the Gulf, the 'miliolite' contains several species of lamellibranchs, including a large cancellated *Lucina* said to occur also at Marbat,[2] a small *Echinus*, corals, and other fossils.[3]

VI. The Conditions under which the Deposits in the Neighbourhood of the Arabian Sea were formed.

I now proceed to discuss the circumstances under which the rocks to which I have referred were deposited. Very little consideration is required to bring us to the conclusion that they cannot all have been laid down in exactly the same manner, or even by the same agency.

Where, as in the case of the hill-deposits of Kach described by

[1] Sometimes called Polior or Pelior. It must not be confounded with the smaller island, Nabiyu Farur (Nobflure) on the south. Surree, another locality for miliolite in the same neighbourhood, is now spelt Seri.

[2] *Venus puerpera*; see [4] A p. 58 & B p. 591.

[3] In these papers Carter seems to regard the 'miliolite' as Miocene, contrary to his views expressed elsewhere.

Prof. Blake, the distribution of the beds can be shown to be closely connected with the direction of prevalent winds in relation to the configuration of the country, a good *primâ facie* case is made out for their æolian origin, which receives strong confirmation from the absence of large marine organic remains, the occurrence of land-shells, and the considerable admixture of arenaceous material, such as might be derived from the dry sandy tracts between the southern seaboard and the hills.

The inland deposits of Kathiawar, described by Mr. Fedden as occurring 'in the gorges of the hills or in patches on their sides like remnants of a snow-drift,' may probably be placed in the same category. They are, I believe, confined almost entirely to the west of Kathiawar, where the meteorological conditions are similar to those in Kach, though the rainfall may not be quite so small.

At Ras Abu Ashrin, on the Arabian coast, the foraminiferal deposits seem to have been to some extent shifted and rearranged by the wind, so that, at any rate, the remanié portion may be considered an æolian formation.

On the other hand, there is every reason to believe in the marine origin of some of the 'miliolite' of the Arabian coast and of the islands of the Persian Gulf. The borings by marine animals, now filled with calcareous material composed largely of foraminifera, reported by Carter from several localities, some as much as 30 feet above the sea [4] A p. 76 & B p. 609, prove that the land has risen considerably in comparatively recent times. It is only natural to suppose that the deposits which are found associated with these borings, and contain numerous mollusca and other marine organisms too heavy to be transported by the wind, must have been laid down in the sea. Further, as it is unlikely that the elevation was purely local, we may assume that all strata of a similar character in that region, containing shells or other fossils larger than the particles of the granular matrix, were formed in the same manner. There is, it is true, the possibility that these beds were thrown up by the waves as beaches of calcareous fragments and shells, but the fossiliferous beds described by Carter at Marbat and Dofar appear to be more extensive and more uniform in character than we should expect in the case of raised beaches.

The deposits which occur along the coast of Kach and Kathiawar present many divergent characters corresponding to the different circumstances under which they were deposited. In some places the preponderance of evidence seems to favour the view that they were formed in the immediate vicinity of the shore by wind-action, for they alternate with arenaceous beds which appear to consist of blown sand; see [9] p. 127. Elsewhere they pass laterally into a sandy deposit resembling a raised beach (*op. cit.* p. 128); and are themselves probably also littoral deposits accumulated by wave-action, and since raised above high-water mark. Some, however, are in the same position between tidal limits (see [8] p. 93) as that in which they seem to have been laid down, and are probably still in course of formation. Many of the beds, on the other hand, were in all probability sediments

deposited in shallow water. The shell-bearing beds on the north of Pacham appear to be an example, and no doubt others will be found when a detailed examination of the strata comes to be made.

The thick homogeneous beds of Ras Abu Ashrin and certain other points on the south-eastern coast of Arabia, which contain no marine shells or other fossils of any kind larger than the minute grains of which the rock is made up, and at the same time no organic remains of terrestrial origin, the Porbandar Stone, and the limestones of Junagarh, Chorwar, and Una, which present similar characters, give rise to greater difficulties; though the position of the limestones of Junagarh and Porbandar west of considerable hills is favourable to the contention that these deposits were accumulated by the south-westerly monsoon wind.[1]

In the first place, the foraminiferal tests and other organic particles which form the nuclei of the grains are undoubtedly of marine origin, being the remains of organisms that lived in the sea. The calcareous envelope, too, surrounding these particles is so similar to that which is found covering grains in admittedly submarine beds, that we may assume that in this case also it was deposited from sea-water.

The question now arises—Were these strata laid down in shallow water, or were the materials of which they are formed thrown up by the waves in a calcareous beach, from which the smaller and more easily transported grains were sifted out by the wind and transported to their present position? The well-developed false-bedding is equally consistent with the action of the wind and with that of varying currents of water saturated with carbonate of lime. It is at first sight strange, if these limestones be subaerial deposits, that there is no record of the occurrence of shells of terrestrial mollusca; but it is not so difficult to account for this, as for the absence of larger marine remains, on the hypothesis that they are strata laid down in sea-water. Land-shells are less numerous than marine forms capable of preservation, and are so fragile that they might easily be destroyed—either by exposure at the surface, or subsequently by the action of infiltrating water. The absence of large marine remains cannot be explained in this way. A considerable part of the rock is made up of minute fragments of the calcareous parts of larger organisms: the action of underground water has not been able to obliterate their structure, and cannot be accountable for the absence of fragments of greater size.[2]

[1] The main mass of the Junagarh Limestone is, however, about $\frac{1}{4}$ mile from the foot of the hills, but much has no doubt been removed by the Sonrákhi River. I have had no opportunity of seeing either the Porbandar Stone or the massive Arabian deposits *in situ*, so must deal principally with the rocks which I have been able to examine; but from the apparent similarity in composition and structure, there is a strong presumption that all the rocks to which I am now referring were formed under the same circumstances.

[2] There are, however, some cases in which strata, supposed to have been formed in the sea and made up of minute particles of marine origin, are practically destitute of larger fossils. In a paper by Mr. Robert Hill on the geology of Jamaica, [51] p. 137, we read:—'As a rule the Tertiary White

The presence in the rock of well-rounded quartz-grains less than 1 millimetre in diameter is strong evidence in favour of a subaerial origin. Such grains are rarely if ever produced by river- or surf-action, but are almost always present in wind-blown sand.

Neither the fragments of igneous origin nor the rounded quartz-grains have a coating of carbonate of lime such as they would have had if they had been present in the saturated sea-water at the same time as the organic nuclei of the calcareous grains. They must, therefore, be additions to the materials of the rock, subsequent to the time when those calcareous grains were removed from the action of sea-water. This circumstance also disposes of any idea, if such were entertained, that the envelope was deposited round the nuclei after the formation of the rock by the action of percolating subterranean water charged with carbonate of lime. What was then added was merely the clear calcite-cement that binds the whole rock together.

There are other points connected with the shape and state of preservation of the foraminifera which support the view that these beds were accumulated by the transporting action of the wind, but they fall within the province of Mr. Chapman's paper: see pp. 584, 588.

It may be objected that any theory which suggests a different origin for deposits that resemble each other so closely as those of Ras Abu Ashrin and Marbat can scarcely be well founded. It must be remembered, however, that, although the source and mode of formation of the grains in the two rocks is, according to the view I have taken, identical, in the latter case they were laid down with marine fossils in shallow water near the shore, and in the former were thrown up as part of a sea-beach and subsequently transferred by the wind to the position in which they are now found.

Although there seems every reason to believe that the Junagarh Limestone was formed by æolian action, considerable difficulties arise, if we assume that the calcareous constituents were transported

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Limestones, which succeed the Cambridge Beds, although almost entirely of organic origin, are singularly free from macroscopic fossils, especially the lower half of the series......Minute search for such fossils in hundreds of exposures has generally been without success......Notwithstanding the absence of macroscopic remains the Montpelier Beds, which compose the lower 500 feet of the White Limestones, are almost entirely made up of foraminiferal remains —*Orbitoides*, *Nummulinæ*, and *Miliolidæ*—at the base, grading up into Globigerinal deposits.' The author attributes the absence of 'macroscopic fossils' mainly to the great depth at which he believes the deposits to have been formed, but he brings no evidence to support this view, which is inconsistent with the character of the foraminifera stated to be present at the base of the Montpelier Beds. In any case the same explanation is not available as regards these limestones in Kathiawar. All our information as to the geology and physical geography of this part of India negatives the idea of such a depression at so recent a period. It is remarkable, however, that these two deposits, the Montpelier Beds and the 'miliolite' of Kathiawar, are both characterized by the presence of *Miliolidæ* and the absence of larger fossils. The possibility of the former being of æolian origin seems at least worthy of consideration. Some of the Jurassic oolites which exhibit false-bedding and are remarkably free from fossils larger than the oolite-grains may, not improbably, also have been accumulated by the action of the wind. See p. 579 of this paper.

by the south-westerly monsoon wind from the present coast-line, as is believed by Prof. Blake to have been the case with the Kach deposits described by him. The calcareous grains that form the Junagarh rock must, in that case, have travelled at least 30 miles overland. But the rainfall near Junagarh is much greater than that in Kach and the western portion of Kathiawar, where the south-westerly monsoon brings but little rain; and there is scarcely any vegetation (except what is the result of artificial irrigation) to obstruct the path of the calcareous particles on their way from the coast. In Central and Eastern Kathiawar the grass and other quick-growing vegetation, which soon spring up under the rains that accompany the south-westerly wind, would effectually obstruct the passage of the calcareous material to the interior of the country. It is true that in the hot weather before the rainy season a sea-breeze blows in the daytime on the coast and reaches Junagarh early in the afternoon, but it would hardly be strong or continuous enough for our purpose so far from the shore. Even if it were, or if the character of the rainfall had changed since the Junagarh Limestone was formed,[1] there is another and quite as formidable a difficulty to meet. Unlike the Kach beds, which, when they are at any considerable distance from the sea, contain a large proportion of extraneous material derived from the intervening country, the strata at Junagarh are on the whole remarkably free from foreign matter except for a few fragments derived from rocks in the immediate neighbourhood. It is impossible to believe that this calcareous material could have been blown for 30 miles over barren plains, without bringing with it a very large admixture of sand and dust. If therefore we accept, as I believe we must, the view that the Junagarh Limestone represents material accumulated by the transporting action of the wind, we must assume that at the time when it was formed the present site of the city of Junagarh was close to the margin of the sea. The land must then have been approximately 150 feet lower than at the present day; and a considerable elevation of the peninsula of Kathiawar must have since taken place—part of the same movement that has raised the Miocene beds of the southern coast-line high above the sea.

The Junagarh beds cannot be of any great age, as their foraminiferal fauna does not differ materially from that now living in the adjoining seas (see Mr. Chapman's paper, p. 585); but it is probable that they are much older than similar beds nearer the coast, and were formed at a time when Kathiawar was an island or group of islands entirely separated from the mainland.[2]

[1] The same considerations apply if we suppose that the calcareous grains were brought by the north-easterly monsoon from the sea which in comparatively recent times must have bounded Kathiawar on the north. It seems not impossible, however, that the deposits on Chotila Hill came from that direction.

[2] Halfway up the central mountain of Girnar is the habitat of a small gasteropod, *Camptonyx Theobaldi* (Benson, 1858). It is the only species of the genus, and no other locality for it is known. Its nearest ally, *Otina*, lives within

VII. Other Tropical and Subtropical Deposits of like Nature.

Calcareous rocks, having many characters in common with those which we have been considering, are found in many other localities in warm countries. I am not aware, however, of any in which foraminifera play so important a part. This may be due to the fact that very few of these deposits have yet been submitted to close microscopical examination, and that each grain is usually surrounded by an envelope of deposited carbonate of lime which hides from view the nature of the nucleus.

These beds may be roughly classified as follows:—

(*a*) Those formed under the surface of the sea, and containing unbroken remains of marine organisms larger than the grains of which the rock is composed.

Deposits consisting of aggregations of calcareous particles derived from the action of the sea on coral-reefs occur in the neighbourhood of almost all coral-islands. It is stated by Dr. Guppy [26] that in the Cocos-Keeling Archipelago such deposits form to the leeward on the flanks of every coral-reef. He intercepted some of the material as it was carried along by the current: it consisted mainly of amorphous calcareous grains, with a small proportion of alcyonarian and sponge-spicules. It would have been interesting to ascertain by the examination of thin sections whether any of these amorphous grains consisted of a calcareous particle as nucleus, surrounded by deposited carbonate of lime, as in the case of the grains of the Junagarh Limestone. There can be little doubt that the banks formed in this way are false-bedded. See also [15] p. 339 & [46] p. 18.

The Nga-tha-mu beds of the island of Kau-ran-gyi (Ko-ran-ji) on the Arakan coast of Burma and the mainland opposite, which are said to resemble the Porbandar Stone, but contain echinoderms, molluscs, and other fossils [21], fall under this heading. They are included in the Pegu Beds, which are supposed to be of Upper Tertiary age.

(*b*) Littoral deposits composed of calcareous material thrown up by the waves.

These deposits resemble in many respects the strata of subaqueous origin included in the previous class. The grains have usually an envelope of deposited carbonate of lime, and oolite-grains are not uncommon. The larger fossils are, as a rule, in a fragmentary condition. Pebbles of limestone as well as of other rocks sometimes

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tidal limits, and there is every reason to suppose that the presence of *Camptonyx* on Girnar dates back from a period when only the upper part of the mountain rose above the sea. I am indebted to Dr. Blanford for the identification of this mollusc, individuals of which were adherent to some of my rock-specimens.

occur: many of these are likewise covered by a calcareous envelope. The stratification is necessarily false-bedded, but the lamination of the most recent layer is usually parallel to the surface of the beach; this is in most cases quite loose above, though a few feet lower down it is cemented into a solid mass, the result of the infiltration of water containing carbonate of lime from the upper part of the deposit. Turtles' eggs are often found, even in the consolidated rock.

Such calcareous beaches are especially characteristic of coral-islands, but are by no means confined to them.

The typical coral-island beach has been well described by Dana [28] pp. 152–54; see also Beete Jukes for the beach-deposits of Raine Island [15]; and Guppy [24] pp. 84–85, for an account of such beaches in the Solomon Islands. Darwin's description of the oolite-beach at Ascension is well-known: see [14] pp. 49–50; [27] A pp. 56–57 & B pp. 198–9; also [11]. A specimen of the Ascension rock, containing remains of turtles' eggs, is in the Museum of the Geological Society. A raised oolite-beach in the Gulf of Suez has been briefly described by Mr. Bauerman [19].

(*c*) Deposits usually found above high-water mark, containing no large marine remains, although the small grains which compose the rock are clearly of marine origin.

These consist for the most part of minute fragments of shells, corals, or limestone, or occasionally foraminifera, which are coated with deposited carbonate of lime exactly in the same manner as in the two other classes; and in this class, too, oolite-grains occur. The stratification is, as a rule, distinctly false-bedded. These rocks appear to be formed, like the Junagarh Limestone, by the action of the wind on the calcareous beach-deposits in sifting out the smaller and more rounded grains, and transporting them inland. In the majority of cases, land-shells or other remains of terrestrial animals are present.

The island of Bermuda [13, 20, 23, 31, 33] and the Bahamas [16, 31] are mainly formed of this rock. Through the kindness of the Council of the Geological Society, I have been allowed to have microscope-sections cut from one specimen of the Bermuda rock and from two specimens of the Bahama rock in the Society's collection. These show great resemblance to the Kathiawar limestones in the well-developed matrix of clear calcite and numerous fragments of marine organisms, with a dark calcareous coating; but in one of the Bahama specimens the oolite-grains are much better developed than is usually the case with the Kathiawar rocks.

Similar deposits also occur in the Canary Islands [12] and at St. Helena [14] pp. 86–89, [27] A pp. 98–101 & B pp. 222–24: see also [22]. Extensive calcareous beds which are supposed to be of æolian origin have been described by Darwin in Western Australia; but he could not find in the grains anything definitely organic [14] pp. 144–48; [27] A pp. 161–66, B pp. 260–63; & [17]. Low

hills of the same composition and origin are also commonly found on coral-islands: see [28] pp. 154–56.[1]

On the shores of the Sinaitic peninsula, near the northern end of the Gulf of Suez, oolitic deposits may be seen in course of formation. The oolite-grains are thrown up on the beach by the waves, and are gathered by the wind into long dunes parallel to the sea-shore. Thence they are blown inland by the westerly sea-breezes, and at Wadi Deheese, $2\frac{1}{2}$ miles from the sea, Prof. Walther found a sandy deposit composed partly of oolitic grains, partly of desert-sands, and it extends still farther inland [29]: see also [19, 25, & 30].

Louis Agassiz [18] has described the formation of oolitic sand-dunes by wind-action in Salt Key between Florida and Cuba. In Double-headed Shot Key these dunes have been consolidated into a hard rock that rings under the hammer. It is 'pretty regularly stratified, but here and there like torrential deposits' (*op. cit.* p. 373), evidently a kind of false-bedding. Orange Key contains the same rock.

VIII. Colder Regions: the Foraminiferal Deposits of Dog's Bay (Galway).

Outside the tropics such deposits as those which we have been considering are, at the present time, of much less importance. Coral-islands, with which they are so often associated, are no longer found. The colder water can dissolve more carbonic anhydride, and therefore more carbonate of lime, without being saturated, and is less liable to concentration by evaporation. Fine-grained calcareous material carried along by moving water will soon be dissolved, and false-bedded limestones will rarely, if ever, be formed under water. Littoral and æolian deposits are, however, occasionally met with.

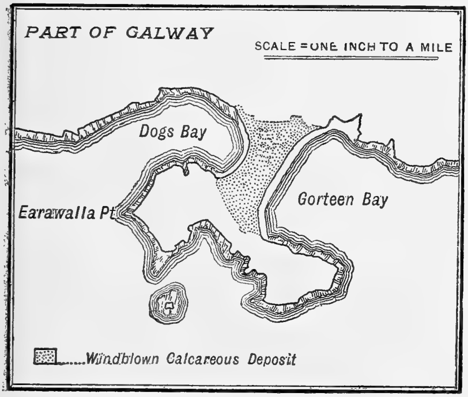
I am informed by Mr. R. Welch, of Belfast, that the isthmus of Earawalla, between Dog's Bay and Gorteen Bay on the south-western coast of Galway, consists of low dunes which are largely calcareous and contain much foraminiferal material. At some points on the Dog's Bay side subfossil land-shells are found embedded in a loamy matrix containing remains of foraminifera. Where sections are available, they do not show the lines of stratification as clearly as in the arenaceous æolian deposits in the North and East of Ireland, but there are brown bands here and there corresponding to former hollows where vegetable matter seems to have collected. Very few, if any, marine shells occur except such as appear to have been derived from kitchen-middens in the vicinity, or may have been carried up by birds for food. The isthmus is about 1000 yards long from north-east to south-west, and about 350 yards in width between the two bays.

Similar deposits are still in process of formation on the isthmus.

[1] [Lantern-slides of calcareous æolian deposits, prepared from photographs taken by Dr. C. W. Andrews in the Cocos-Keeling Archipelago, were exhibited at the meeting at which this paper was read.]

The surface-drift in the North Atlantic, doubtless with the assistance of local currents, brings a plentiful supply of foraminifera into Dog's Bay, and every high tide spreads them over the gently sloping strand, where they are associated with numerous small gasteropoda (*Rissoa*) and other larger shells. In fine, warm weather they rapidly dry, and are carried landward by the wind before the tide again advances. Sometimes, when a slight shower has washed the minute calcareous particles free from salt, almost the whole surface of the strand may be seen moving steadily up beyond high water, rolling into and filling any hollows in the path with pure wind-drifted foraminifera and ostracoda (mostly snowy-white) and finely comminuted shells. In high winds much of the foraminiferal material is blown right across the isthmus to Gorteen-Bay strand and into the sea beyond, where it can be sometimes seen floating upon the surface of the water.[1]

Fig. 4.



The foraminifera of Dog's Bay are not surrounded by an envelope of deposited carbonate of lime: hence we may draw the conclusion that the water in the bay was not saturated with it; and whatever may be the case at other places, there is not here a subaqueous deposit forming in the bay similar to that accumulated by wind-action on the isthmus, for the continual movement of tidal currents would be sufficient to keep the foraminifera in motion until they were dissolved.[2]

An ancient beach made up of foraminifera and comminuted shells, with rounded fragments and pebbles of non-calcareous rocks, was described by Prestwich from Barnstaple Bay, and seems to represent an ancient deposit similar to that at Dog's Bay. It is

[1] This description is extracted from Mr. Welch's letters to me. He briefly refers to the subject in a paper on 'Land-Shell Pockets on Sand-Dunes' [40]. The foraminifera are enumerated by Mr. Joseph Wright [37], and Messrs. Standen & Collier have dealt with the mollusca [38 & 39] from the same locality. The isthmus is mapped by the Geological Survey of Ireland as blown sand [34]. In the accompanying memoir [35] we read: 'Some of the meteoric drift is represented by tracts of æolian or blown sand, both siliceous and calcareous. This occurs principally near the coast, but it is also found in some of the inland valleys.'

[2] It is true that the foraminiferal tests washed ashore have arrived practically uninjured from a long sea-journey, but they were probably protected by organic material still adherent to them.

covered by a considerable thickness of false-bedded blown sands, with occasional marine and numerous land-shells [36].

I am indebted to Mr. Chapman for the perusal of a paper by Messrs. Rogers & Schwarz, describing the occurrence of extensive false-bedded deposits near Cape Town (South Africa), formed almost entirely of comminuted marine shells and containing in places the bones of land-animals. The authors believe these beds to be of æolian origin [41].

IX. The Oolites of the Jurassic Period.

Many writers have called attention to the resemblance between the Jurassic rocks above the Lias and the deposits now forming among the coral-islands of the tropics.[1] All the calcareous beds afford evidence of the deposition of carbonate of lime from solution, either as a simple envelope covering organic particles, or in the form of well-developed oolite-grains. False-bedding is often present, especially where the rock is largely made up of oolite-grains or fragmentary organic remains: see [45] p. 282.

All the three classes, distinguished in this paper among granular calcareous deposits accumulated in tropical or sub-tropical regions, appear to be represented among the Jurassic limestones.

Many of the Oolite-beds contain numerous uninjured shells of mollusca, and we have every reason to suppose that these were formed under the sea. The occurrence of calcareous mud between the oolite-grains or other particles of which the rock is made up, would point to a submarine origin, though it might sometimes be present in beach-deposits.

Elsewhere we have clear evidence that the beds were originally a littoral formation. In 1862 James Buckman described the occurrence of reptilian eggs of elongated shape (*Oolithes bathonicus*) in an obliquely laminated freestone a little below the top of the Great Oolite at Cirencester [42]. He considered that the rock had been accumulated on a 'widely shelving beach' or in a very shallow sea. Rounded eggs resembling turtles' eggs were afterwards described by Mr. Carruthers [43] from the Stonesfield Slates (*O. sphæricus*): remains of turtles are found in the same bed. At the present time turtles bury their eggs in the beach-sand just above the high-water mark for spring-tides, and the crocodilia select a similar position by the river-margin. The Stonesfield Slates therefore, and the egg-bed of the upper portion of the Great Oolite, represent gently-sloping beach-deposits, part at least of which must have been raised above the reach of the waves.[2] In other places, where the rock contains numerous broken shells larger

[1] See [46] pp. 16–21, and references there given.

[2] It is hazardous to argue from the habits of recent reptiles to those of the Jurassic period; but it is scarcely conceivable that a reptile, the young of which breathe air from the time when they leave the egg, should lay its eggs where they would be submerged at high tide.

than the oolite-grains, it may represent another phase of beach-formation. In some parts, for instance, of the Great Oolite the organic remains are so broken up, that hardly a single perfect specimen can be found: see [45] p. 298.[1] The Forest Marble likewise contains in places large quantities of broken shells (*ibid.* p. 305).

There seems every reason to believe that æolian deposits, too, are not wanting among the Jurassic oolite-rocks. Oolitic grains are, from their size and shape, especially susceptible of transport by the action of the wind, and grains consisting of organic or other particles, with a single coating of deposited carbonate of lime, are sufficiently rounded to be transported almost as easily. When a rock is found to be made up almost entirely of such grains, without larger fossil remains, we may suspect that it was formed by wind-action.[2] This presumption is strengthened where the cement, binding the grains together, is comparatively clear calcite, as in the Junagarh and other Kathiawar æolian limestones (see also [52] p. 103), and does not consist of turbid consolidated calcareous mud, as in the case of some oolitic limestones [46] pp. 8, 12, which must, as I have said, have been deposited as submarine or littoral deposits. The exceptional Oolite-rocks in which there is no cement whatever, [46] p. 12, are probably also of æolian origin.[3]

We have seen that at the time when the turtles' and other reptilian eggs were buried, the calcareous beach-deposits of the Bathonian Epoch, in which they are now found, must in all probability have been situated near the sea-margin, a little above high water, in just such a position as we might expect wind-borne material to accumulate; for the line of high water at spring-tides is often marked on low shores by a ridge of sand.[4] We ought not, therefore, to be surprised if the strata succeeding the beds in the Great Oolite Series, where these reptilian eggs occur, prove to be of æolian origin. At various points in the Great Oolite the rock does in fact exhibit many of the characters of a wind-formed deposit In hand-specimens it shows a remarkable resemblance to some of the Kathiawar and West-Indian æolian rocks, and in some cases,

[1] The conglomeratic structure sometimes seen in the Great Oolite also points to littoral deposition.

[2] The thin delicate shells of oceanic gasteropoda and certain other mollusca, although of fairly large dimensions, may sometimes be blown inland [23] p. 321, but, like land-shells, are liable to be destroyed before the consolidation of the rock, or obliterated by recrystallization. The presence of a few isolated shells may also be explained by the action of shellfish-eating birds or animals (see p. 576 of this paper). Hermit-crabs are responsible for some marine gasteropods in recent æolian deposits [23] p. 321.

[3] Mr. Horace B. Woodward, in describing the deposits characteristic of coral-islands, refers to the false-bedded calcareous æolian rocks of the Bahamas, and quotes Dana to the effect that similar rocks are frequently oolitic. He afterwards remarks that 'it is a study of these sedimentary and other accumulations due to the destruction of coral-reefs that will help to explain the origin of our oolitic deposits.' But he appears to consider 'the false-bedded character of so many of the Oolites' as exclusively a subaqueous phenomenon: see [46] pp. 17–18.

[4] Much of the foraminiferal material in Dog's Bay is accumulated just above high-water mark.

where the oolitic character is strongly developed, the larger fossils are almost entirely absent.

I have recently had the opportunity of examining some of the false-bedded strata in the Great Oolite near Cirencester. They are well seen in the quarry in Hare Bushes Wood, east of the town.[1] Here two series of false-bedded strata occur, separated by beds showing the true stratification. There are no fossil-fragments which could not have been easily transported by a moderately strong breeze. The false-bedding dips at an angle of about 20° north-eastward. As the true dip is very slight, the inclination and direction of the bedding-planes represent, approximately, the original dip of the false-bedding; so that if these strata are of æolian origin, they afford evidence that the prevalent winds blew from the south-west, as at present. Microscope-sections of the upper false-bedded strata showed the clear calcite-matrix and other characters distinctive of the Kathiawar and West-Indian rocks: the oolite-structure was not, however, quite so well developed as in the Bahamas rocks. Microscope-sections from the quarry by the cross-roads south-west of Baunton Downs, [46] p. 284, north of Cirencester, showed somewhat similar characters. Throughout the district the prevailing dip of the false-bedding is north-easterly.

Through the kindness of Mr. Teall, I have had an opportunity of examining numerous microscope-sections of the rocks of the Great Oolite in the possession of the Geological Survey of the United Kingdom. Many of these are in every way similar to those that I have described from the neighbourhood of Cirencester, and to the æolian rocks of the West Indies and Kathiawar. The worn character of some of the grains[2] suggests abrasion by wind-action. Siliceous sand-grains only occur occasionally, and are seldom well-rounded; but that is to be expected on the shores of a coral-island composed almost entirely of calcareous material, as it is of course the mutual friction of minute particles of silica and equally hard rock-masses in desert-areas which effects the rounding.

The false-bedded Oolites which succeed the Stonesfield Slates with their turtles' eggs, and the 'decidedly oolitic' freestone with oblique bedding that overlies the *Oolithes-bathonicus* Bed in the upper part of the Great Oolite, are therefore not improbably of æolian origin; and the Great Oolite Series, from the Stonesfield Slates to the Forest Marble, would appear to represent an alternation of littoral and subaerial deposits, with occasional intercalation of shallow-water marine beds. The markedly lenticular character of the more oolitic beds is in accordance with this view.[3]

[1] They occur at an horizon which has been included by Prof. Hull in the Forest Marble. This quarry is in the wood north of the main road, and is distinct from the Hare Bushes Quarry south of the road in which, I believe, the reptilian eggs were found; see also [46] p. 284.

[2] See [44] p. 83, and Mr. Chapman's paper, pp. 584–85 of this volume.

[3] See [46] pp. 248–49, 250–59, 271 & 290. These calcareous æolian strata were probably accumulated under conditions more closely allied to those which obtain in the case of the calcareous dunes of coral-islands, than to those of the deposits in the more hilly parts of Kathiawar and Kach.

The fact that æolian calcareous rocks are not more frequently recorded from the sedimentary rocks is easily explained. In the first place, like all terrestrial deposits, they are not favourably situated for preservation. If the land is sinking, they are liable to be destroyed by wave-action as the sea advances; while, if the land is rising or stationary, they are exposed to the destructive action of subaerial agents, to which they are especially susceptible. The almost complete absence in temperate regions of recent deposits of this description, and consequent want of familiarity among geologists with their characteristics, may, in some cases, have prevented their recognition. A careful examination of the limestone-rocks in the light of the æolian deposits that have been described from so many parts of the world, may lead to the identification of still further examples dating from a more or less remote past.

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[For the Discussion, see p. 588.]

30. NOTES *on the* CONSOLIDATED ÆOLIAN SANDS *of* KATHIAWAR. By FREDERICK CHAPMAN, Esq., A.L.S., F.R.M.S. (Communicated by Dr. J. W. EVANS, LL.B., F.G.S. Read June 6th, 1900.)

[PLATE XXXII.]

IN Kathiawar and Kach, on the littoral between the peninsula of India and the mouth of the Indus, are some interesting calcareous deposits which, both in structure and composition, present many points of interest. They are usually known under the name of the Miliolite-formation, given by H. J. Carter, who was the first to investigate them.

Dr. J. W. Evans, who was formerly State Geologist to the Government of Junagarh in Kathiawar, has supplied me with four specimens from different localities in the Junagarh State, as well as a microscope-section made in India. I am indebted to Prof. T. Rupert Jones for another specimen from the hills north-east of Porbandar. I have carefully examined these specimens for organisms, both in thin sections and in the disintegrated rock.

The material investigated by Carter was from the locality near Porbandar, where it is quarried and exported for building purposes under the name of Porbandar Stone. He refers to it as follows [1]:—

> 'The Poorbandar limestone derives its specific denomination from the place near which it is quarried in Khattyawar, and is imported at Bombay in the shape of blocks and flags for building purposes. It is of a brownish-white colour, uniform in structure, granular, and composed of oolitic particles of calcareous sand united together into a firm compact rock.'

On examination by Dr. Carter it yielded numerous foraminifera, among which those of the genus *Miliolina* were conspicuous. The rock, however, resembles the Miliolitic Limestone of the Paris Basin neither in age nor in structure.

There cannot be the slightest doubt that the organic remains found in the rocks that I am about to describe must have originally inhabited moderately shallow to littoral marine areas. The question arises as to whether the materials of these rocks were deposited in the localities where the organisms lived, or whether they were accumulated on the land by æolian agency. Microscopical examination of the minute granules reveals the fact that they are in most instances worn and polished: this points to the conclusion that they have been abraded by being rolled along by the transporting action of the wind. The rounded shape of the prevailing genera would facilitate such movement; the absence of larger remains supports the same view; while the false-bedding might be due either to wind- or current-action. These rocks, therefore, appear to represent an accumulation of material derived from littoral calcareous

[1] Journ. Bombay Branch Roy. Asiat. Soc. vol. iii, pt. i (1849) p. 170.

sand of marine origin, mixed with a varying proportion of mineral detritus from adjacent hills. It is possible that some of the Kathiawar calcareous rocks may have been deposited in shallow water, but there is no satisfactory evidence of this in any of the specimens that I have had an opportunity of examining.

With regard to the age of these rocks, I do not think that they can be older than late Pliocene, and there is nothing in the general character of the organic remains which is inconsistent with a still more recent origin.

From the Porbandar limestone Dr. Carter obtained very perfect brown casts of the foraminifera, by treating the rock with acid, and these casts he compares with those described by Mantell under the name of molluskite (*loc. cit.*). It is quite probable that in all those cases where the body-cavities in organisms are infilled with limonitic and hæmatitic substances, or with the yellow, brown, or green varieties of glauconite, that the decomposing animal matter within the test has started the reaction which results in the deposition of the mineral; but it hardly appears correct to suppose that the actual sarcode-body of the animal has become mineralized as these authors suggest, since the sarcode or other organic substance would certainly shrink on the death of the organism, and not fill the cavity. The specimen of rock in the present series which best shows these casts is that marked III, 165 A, from near the Girnar Hills (p. 586).

In the following description of the various specimens examined, I give the reference-numbers placed upon them by Dr. Evans.

I, 283 Q; near the Girnar Hills, about 30 miles from the sea.—A pinkish or cream-coloured calcareous sandstone, looking somewhat like a fine-grained Bath oolite. It is quite friable, and small pieces can be reduced to powder by pressure with the fingers. This rock, seen in thin-sections under the microscope, is composed of granules for the most part of an organic nature, but with a fair proportion of mineral particles: the latter are described by Dr. Evans (see p. 564). The grains average about 1·5 mm. in diameter, and are embedded in a minutely granular matrix of calcite. The foraminifera are well seen in the section, and associated with these are some more or less flaky pieces of molluscan shells often filled with the borings of a thread-like alga or fungus, and some spines of echinoderms.

The crushed material from this rock has yielded the following species of foraminifera, much worn and polished, apparently by æolian action:—

Miliolina trigonula (Lamarck). Common.
Miliolina sp. near *oblonga* (Montagu). Frequent.
Discorbina Berthelotiana (d'Orb.). Rare.
Truncatulina Ungeriana (d'Orb.). Rare.
Pulvinulina repanda (F. & M.). Frequent.
—— *elegans* (d'Orb.). Rare.
Rotalia orbicularis (d'Orb.). Rare.
—— *Beccarii* (Linn.). Rare.

Nonionina communis (d'Orb.). Frequent.
Polystomella striatopunctata (F. & M.). Common.
Amphistegina Lessonii, d'Orb. Common.
? *Operculina* sp. Very rare.

There were also present in the crushed material several specimens of ostracoda, much worn and polished, and apparently belonging to the genera *Paracypris*, *Cythere*, and *Cytheridea*.

II, Junagarh. Near the Girnar Hills.—A granular calcareous rock, but with mineral particles derived from igneous rocks, cemented by calcareous material. One can distinguish many specimens of foraminifera, including *Pulvinulina* (thick forms, littoral rather than pelagic in habitat). Numerous fragments of lamellibranch- and gasteropod-shells are also present in this rock.

III, 165 A. Near the Girnar Hills (3 miles away); about 30 miles from the sea.—A gritty or pebbly calcareous rock of a pale ochreous yellow, very incoherent in texture.

This rock differs in several points from the preceding. It is composed of coarser granules, and the calcitic cement is more coarsely crystalline. Molluscan shell-fragments are numerous, as also echinoderm-spines, with occasional fragments of *Lithothamnion*. It is this rock that shows the best examples of the infilling of foraminifera. The latter are numerous, and in the rock-sections one may detect *Miliolina*, *Globigerina*, *Rotalia*, and *Amphistegina*. These forms are fairly common, with the exception of *Globigerina*, of which there is only one example. I have obtained some very perfect and beautiful casts of foraminifera from this rock by treating it with acid; with these occur also casts of the borings of the perforating alga in the molluscan shells, and many echinoderm-spines, similar to that figured by Carter,[1] but ascribed by him to ? *Nodosaria spinicosta*, d'Orb. These casts are apparently composed of limonite and hæmatite; and Carter also found this latter mineral constituting the casts.

Besides the mineral particles, which Dr. Evans has found to be derived partly from quartz-keratophyre and partly from basalt, there are oolitic granules, and a large number of coprolitic (?) bodies of an ovoid shape.

The separate grains forming this rock are somewhat rolled, but are not coated with secondary mineral matter, being merely cemented in the matrix.

IV, 279 M. Chorwar Road, nearly 10 miles from the sea.—A yellowish, almost salmon-coloured limestone, too compact to be termed a calcareous sandstone, somewhat cavernous.

In this rock there is more cementing-material than in the two preceding, and the calcite is clearer and more definitely granular. The organic and other particles are here distinctly outlined with a

[1] Journ. Bombay Branch Roy. Asiat. Soc. vol. iii, pt. i (1849) p. 171 & pl. ix.

thin deposit of a dark colour. The foraminifera are numerous, comprising *Truncatulina*, *Pulvinulina*, *Rotalia*, and *Amphistegina*. Associated with these are numerous rounded pellets (? excretionary), molluscan shell-fragments, a small gasteropod-shell, and echinoderm-plates.

V, 279 O. Chorwar Road, nearly 10 miles from the sea.—A cavernous, semicrystalline limestone, having the walls of the cavities stained with ochreous matter. This is a more coarsely crystalline development of the preceding rock, and differs in the larger proportion of material derived from molluscan shells. Somewhat flaky fragments of these form the majority of the included particles of this rock. There are also present bone-fragments and echinoderm-plates and spines. Foraminifera are exceedingly rare, and represented only by *Amphistegina*. The matrix appears to be clear granular calcite, and constitutes perhaps 50 per cent. of the bulk of the rock. (See Pl. XXXII, fig. 1.)

VI, Porbandar Calcareous Rock.—This is one of those rocks especially referred to by Carter as coming from Kathiawar, and used for building-stone. The present specimen was given to Prof. Rupert Jones by the late Henry Hailes in 1886. It is a white calcareous rock, interspersed with red particles. The rock itself is homogeneous in character, and when two pieces are struck together they sound with a distinct, musical 'clink.' Thin sections of this rock seen under the microscope are of a yellowish colour, and suggest partial phosphatization. They show a very evenly granular structure, the granules being cemented in a clear crystalline calcitic matrix. The granules consist of foraminifera, gasteropod and lamellibranch shell-fragments, echinoderm-plates and spines, coprolitic (?) granules, oolitic grains, and some fragments of *Lithothamnion*. The foraminifera belong chiefly to the genera *Miliolina*, *Pulvinulina*, and *Rotalia*. The granules are all neatly rounded, or when elongate, rounded at the extremities, and they are all invested with a thin dark layer which seems to be the first stage towards an oolitic structure. (See Pl. XXXII, fig. 2.)

Postscript.

Since writing the foregoing notes I have received an interesting paper from Mr. E. H. L. Schwarz, entitled 'Notes on the Recent Limestones on Parts of the South & West Coasts of Cape Colony' by him and A. W. Rogers.[1] It deals with some coastal deposits formed as sand-dunes, showing false-bedding, and with included marine shells, land-shells, and mammalian bones. The upper portions of these deposits are hardened by the percolation of surface-water, which dissolves and redeposits the carbonate of lime. This occurrence seems to throw additional light on the mode

[1] Trans. S. Afric. Phil. Soc. vol. x (1898) pp. 427–36 & pl. x.

of formation of the rocks from India just described, and seems to be in some respects a parallel case.

In concluding these notes I may briefly refer to the foraminiferal wind-borne sands of Dog's Bay (Galway), which Dr. Evans has already mentioned. These sands are an almost pure foraminiferal deposit, and consist largely of sub-globular *Miliolinæ* and the inflated *Truncatulina lobatula*. As in the case of the foraminifera of the Kathiawar rocks, where the genera are of the Milioline or the Rotaline types, the deposits at Dog's Bay are composed of those forms which are very susceptible of movement by the slightest breeze that blows upon them, and causes them to creep along in the direction of the wind.

EXPLANATION OF PLATE XXXII.

Fig. 1. Microscope-section of cavernous semicrystalline limestone from Chorwar Road. ×36.

2. Microscope-section of calcareous rock from Porbandar. ×30.

Discussion on the two foregoing papers.

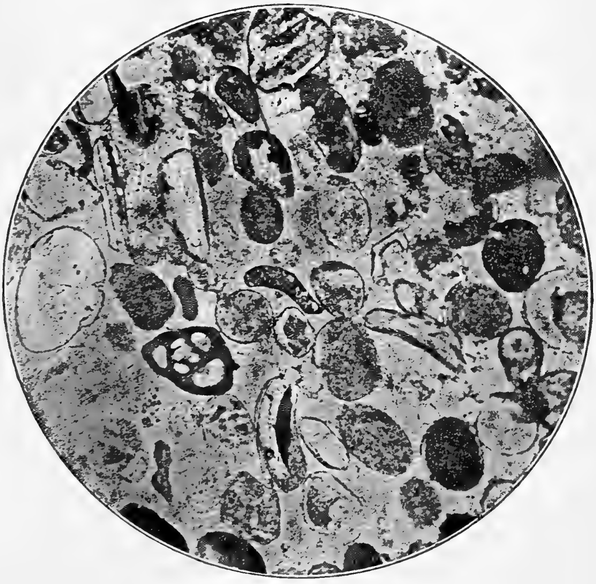
Prof. Hull thought Dr. Evans's paper very suggestive; but he was unable to accept his views, unless to a very limited extent. As regards the oolitic limestones on the coast of the Red Sea and along the Sinaitic peninsula, described by Prof. Walther, he had not had an opportunity of personally examining them, but he had understood that they were distinctly coralline raised-beaches. It was unquestionable that the whole of that region had been elevated from below the waters of the sea in late Pliocene times as shown, among other cases, by the raised beach of Jebel Mokattam above Cairo (first described by Dr. Oscar Fraas) at a level of 220 feet above the surface of the Red Sea. With regard to the suggestion of Dr. Evans that some of the Oolite-limestones of England, characterized by oblique lamination, were of æolian origin, he (the speaker) thought that possibly some of the lower beds of the Great Oolite on the horizon of the Stonesfield Slate might have been moved by winds when left dry during the recession of the tides, as these were doubtless shallow-water deposits; and, finally, he desired to point out that absence of marine shells or fossils from certain strata by no means indicated that these strata were not of marine origin, as the calcareous matter of which they are formed is liable to be dissolved away by subaerial waters.

The Rev. J. F. Blake said he was gratified that Dr. Evans had been able to adopt the view of the æolian origin of the Porbandar and Junagarh limestones. He was not sure of the necessity of the sea being nearer at hand during the formation of the latter. If the intervening land was covered with the usual fine alluvial soil, the wind might have a selective action, blowing away the finer dust while it deposited the coarser shell-grains against the hill-side. He had not been able to recognize among the Jurassic rocks of

1. × 36.

CHORWAR ROAD.

2. × 30.



F. Chapman Photo.

PORBANDAR.

CONSOLIDATED CALCAREOUS SANDS OF KATHIAWAR.

England any that were specially of æolian origin, though as winds might blow from land to sea some contributions from this source were to be expected. The special features, however, that had led to the idea of the æolian origin of the Indian deposits were not present among our English Jurassics, none of which showed the considerable vertical thickness associated with limited horizontal extent, or the presence of a mass of older rock at their margins. Even those that showed false-bedding mostly contained, as at Sturminster Newton, remains of larger organisms.

The PRESIDENT and Mr. C. W. ANDREWS also spoke.

Dr. EVANS, in reply to Prof. Hull, said that the absence of large marine fossils in the Junagarh Limestone could not be accounted for by the subsequent alteration of the rock, as minute fragments of lamellibranch- and gasteropod-shells could be seen scattered through the rock, and these still preserved their characteristic structures. He had never asserted that the whole of the Great Oolite beds were of æolian origin, but thought there were good grounds for believing that portions were of that nature.

In reply to Prof. Blake, he contended that if the calcareous materials forming the Junagarh Limestone had been blown across the country between the sea-coast and Junagarh, they must have included materials from the Deccan Trap which was exposed in that district. It was true that the false-bedded Jurassic Oolites had a greater lateral extension than the Junagarh or Porbandar rocks, and were not banked up on the windward side of older elevations; but in these respects they resembled the granular calcareous rocks of Chorwar and other localities south of Kathiawar, which showed the same microscopic structure as the Junagarh rocks.

31. *On* Ceylon Rocks *and* Graphite. By A. K. Coomára-Swámy, Esq., F.G.S. (Read June 6th, 1900.)

[Plate XXXIII.]

Contents.

I. The Physical Geography of the Area.

Ceylon is almost connected with India by the Manaar and RamesWaram Islands and the reef known as Adam's Bridge: there is no channel deep enough for large steamers to pass. Nearly four-fifths of its area is a flat 'low country' forming a maritime belt in the south, and covering a greater area in the north. The main mountain-massif, consisting of ancient crystalline rocks, is situated a little south of the centre of Ceylon in the South Central, Uva, and Sabaragamuwa provinces. In this area rise lofty and often precipitous mountains, of which the highest is Pidurutalagalla, 8296 feet above sea-level; while Adam's Peak reaches 7353 feet. In between these peaks stretch considerable tracts of tableland or rolling grassy plains (Patanas), such as the Newera Eliya Plain, at an altitude of 6200 feet, or the Elk and Horton Plains, over 7000 feet. The rainfall in these districts may exceed 280 inches per annum, while it is only 50 inches in the northern flat, dry country. The rivers rise in the mountainous districts, running at first through rocky gorges, forming striking waterfalls, but meandering slowly through alluvial flats when they reach the low country.

Ceylon is essentially a continental island, and, as we should expect, shares to a great extent the flora and fauna of India. It is, however, remarkable that nearly 30 per cent. of Ceylon phanerogams are endemic, and the same is true of 2 per cent. of the genera [13].[1] This fact indicates a not very recent separation from India, indeed it is evident that Ceylon has risen in quite late geological times. This is shown by the extensive areas of recent marine deposits which are found fringing the coast, and in the north covering a larger area. Probably the same is true of Southern India. A depression of a few hundred feet affecting Ceylon and Southern India would submerge much of the low country (which

[1] The numerals between brackets throughout this paper refer to the bibliographical list on p. 612.

lies especially in the north), and would separate Ceylon from India more effectually than is now the case.

Thus endemic species which appeared while Ceylon was farther removed from India than at present, would not have been able to spread to the Peninsula as easily as would now be possible. The elevation may be comparatively recent, and is perhaps still going on.

Previous to 1887, remarks on the geology of Ceylon which have been made in books dealing with the island have been of a general character. The articles on the geology in the works by Sir Emerson Tennent [6] and 'An Officer of the late Ceylon Rifles' [9] are worthy of note. Since then, important contributions to our knowledge of Ceylon geology have been made by Sandberger [14], Lacroix [17], Walther [18], Melzi [29], and Diersche [30]. No geological survey is in progress in Ceylon, and it is much to be hoped that the Government will soon realize the importance of instituting one.

My thanks are due to Major-General F. T. Hobson, F.G.S., who kindly accompanied me to the Mahara Convict-quarry; to Mr. Edgar Ferdinand of Kurunegala, who showed me the Ragedara graphite-mines; also to Mr. Peter D'Abrew of Colombo, to Mr. Modder of Kurunegala, to Messrs. Casa Lebbe & B. Weerasiri of Kandy, to Mr. Kellow of Hakgala, to Mr. B. Seneviratne of Galle, to Mr. Hector van Cuylenberg of Colombo, to Messrs. A. A. C. W. Jayasekara & L. S. Amarasekara, and to Mr. Bell, Archæological Commissioner.

In England my thanks are especially due to Prof. Bonney, who has most kindly superintended the writing of this paper, which could not have been prepared without his assistance, and who allows me to say that the petrological determinations [1] made in it have his approval; to Mr. Teall, who has also very kindly given assistance and advice; to Mr. R. Graham, who kindly measured the crystals; and to Mr. S. Hastings, of Middlesex Hospital, who analysed a pyroxene.

II. The Recent Deposits.

The greater part of the coast is fringed by coralline raised beach, and in the north a large area consists of bedded sea-sand and coralline limestone. In going by rail from Colombo to Galle, numerous diggings in the rubbly coral-limestone are seen; it is burnt for lime which is used in building or as a constituent of a chewing-paste. In some places considerable areas of pure sandy deposits are found, as in the Cinnamon Gardens, Colombo, where the soil is said to contain 98 per cent. of silica.

[1] [It may be mentioned here that details of pleochroism, extinction-angle, etc. are not given in the descriptions when they are quite normal, but that the determinations are based on the careful use of the usual methods, including examination in convergent polarized light. The figures given in parentheses after the word 'plagioclase' in many cases serve to indicate the highest measured extinction-angle from albite-lamellæ, in each instance.—July 2nd, 1900.]

Laterite (cabook), red or mottled red-and-yellow, occurs abundantly, often of considerable thickness, resting upon, and resulting from the decomposition of, the crystalline rocks. The less easily decomposable minerals, such as tourmaline and graphite, are sometimes found in it.

The rivers, as they approach the sea, flow through alluvial flats of their own deposition. Farther inland coarse gravels are found, or alternations of muddy and sandy or gravelly deposits. Thus the promontory, formed by the loop of the river flowing round the Peradeniya Gardens, consists of coarse crystalline gravel, which is found perhaps 50 feet above the present level of the Mahaweli Gorge. The Newera Eliya Plain consists of alternations of muddy and sandy or gravelly deposits.

With the exception of moonstone, all the gems for which Ceylon has long been so famous are found in drift-deposits, especially near Ratnapura and Rakwana in the Sabaragamuwa district. Here the gravels are very extensively dug, and gems of great value are discovered from time to time, while stones of less value are very abundant. The gem-stones include ruby, sapphire, white and yellow corundum and 'star-sapphires,' chrysoberyl, cat's-eye, alexandrite, iolite, zircons of varied colour, tourmalines, blue and red spinels, garnet (precious and cinnamon-stone), and topaz.

Of the rough gems occurring in the gravels at Ratnapura and Rakwana, corundum is abundant and very often in good crystals which are quite large, reaching $4\frac{1}{2}$ cm. in diameter and 9 cm. in length. Hexagonal prisms and pyramids are the usual forms. Twinned crystals occur, but are rare. The smaller, or less-worn crystals have sometimes very brilliant unscratched faces and sharp edges. The following combinations were measured by Mr. Graham:—

$(11\bar{2}0)(10\bar{1}1)(22\bar{4}3)(44\bar{8}3)$; $(0001)(0\bar{1}\bar{1}1)(11\bar{2}1)$; $(0001)(22\bar{4}3)(11\bar{2}0)$; $(0001)(10\bar{1}1)(22\bar{4}1)$; $(0001)(10\bar{1}1)(44\bar{8}3)$.

Zircon is abundant, and usually of a characteristic brown colour, prisms and pyramids being the commonest form. Twins occur. A twin on (101) included the forms (110), (111), (101), (311). Other crystals showed various combinations of the forms (100), (110), (101), (111), (311), (331), (221); all these were measured by Mr. Graham.

Spinel occurs in rolled octahedra or irregular pieces.

Gold has been occasionally found in very small quantities in the sands of Ceylon rivers.

Apparently diamonds have never been found in Ceylon.

III. The Crystalline Rocks.

(1) Pyroxene-Granulites.

This rock-type is widely distributed in Ceylon, occurring at Newera Eliya, Kandy, Ragedara, Dondra Head, Matara, Galle, and Colombo. The rock as seen in Ceylon is usually dark, and has a

characteristic greasy look. As a rule, foliation is not evident macroscopically, but it may appear in the thin slices. The minerals most frequently present include pyroxene (augite or hypersthene, or both), felspar (plagioclase, usually labradorite; more rarely orthoclase-microperthite), garnet, quartz, amphibole, magnetite, biotite, apatite, and zircon. Of these the pyroxene and felspar alone are essential constituents; in the absence of quartz and garnet the rocks approach gabbro, while varieties consisting chiefly of pyroxene and garnet are near to eclogite. The structure is often granulitic, the minerals being much interlocked, and the quartz-grains elongated as in the normal granulites; or it may be merely granular. Centric structures taking the form of pyroxene-felspar-intergrowths surrounding garnets are very characteristic of some varieties. In the Ragedara granulite the felspar is orthoclase-microperthite, and the garnets are intimately associated with brown mica. The centric structures appear to have arisen in connexion with the corrosion of the garnets.

Among the specimens collected three types are recognizable :—

(i) Plagioclase-bearing pyroxene-granulite with centric structures;
(ii) Orthoclase-bearing pyroxene-granulite with centric structures; and
(iii) Granular pyroxene-granulites without centric structures.

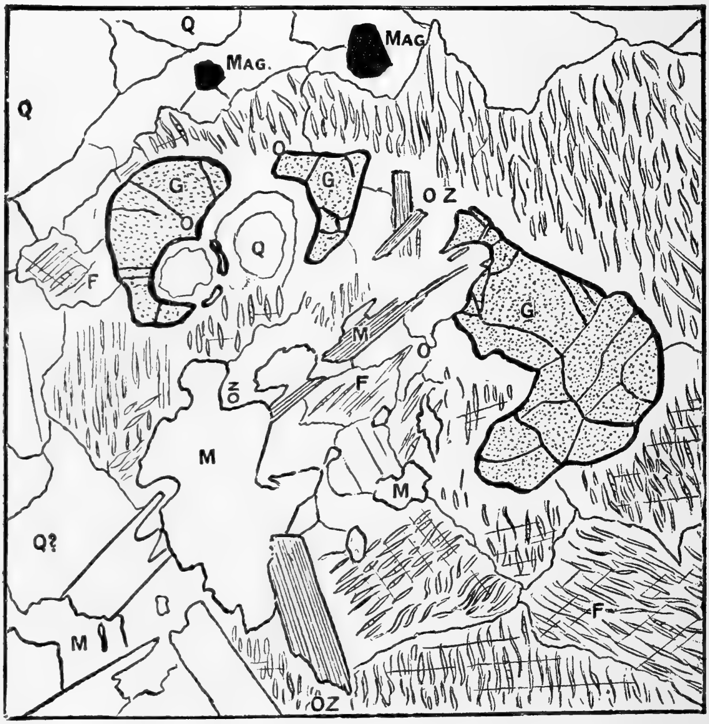
TYPE 1. Newera Eliya.—A specimen collected on the path leading up Pidurutalagalla, about one-third way from the summit, has proved interesting. The rock is dark green, and contains dark red garnets. The minerals are hornblende, pyroxene (chiefly green augite; a little hypersthene), plagioclase (27° 27°, probably labradorite), magnetite, apatite, and zircon. The garnets are not quite evenly distributed. In parts free from garnet, hornblende is more abundant than augite, and these two minerals, with plagioclase and quartz, compose a granular rock. In the neighbourhood of the garnets, augite is far more abundant than hornblende, and magnetite becomes conspicuous. Some parts consist almost entirely of garnet and augite, thus resembling eclogite. Throughout there is a limited amount of a pleochroic (pink to sea-green) pyroxene, probably hypersthene. Only when the garnets are in contact with plagioclase rather than augite are the remarkable coronas seen. These consist of radiating fingers of pyroxene (augite, hypersthene) proceeding from the garnets and standing out against a plagioclase-background, the plagioclase showing between crossed nicols the usual twin-lamellation, which is not interfered with by the fingers of pyroxene. The larger magnetites of early consolidation are curiously related to the garnets. They are quite irregular in shape, and occupy bays and depressions in the garnets, but are separated from them by straits of plagioclase constant in width. The garnet appears to have been moulded on the magnetite, and subsequently separated from it by a narrow strip of felspar. From the almost ophitic way in which the plagioclase associated with the coronas and straits occurs, it appears to have been the last mineral to consolidate (Pl. XXXIII, figs. 3 & 4).

Ragedara.—In one specimen from Ragedara somewhat similar

appearances are seen. Some of the garnets are surrounded by irregular graphic intergrowths of augite, biotite, magnetite, and plagioclase. The larger grains of magnetite are either included in the larger garnets or in the augite. In the latter case they are almost always separated from the augite by a narrow rim of garnet.

Kandy.—A very dark pyroxene-granulite from the 'Mica Estate' at Talatuoya shows traces of a similar structure. In this rock the pyroxene, though pleochroic, appears to be monoclinic.

Fig. 1.—*Corroded garnet* (G), *associated with brown mica* (M) *and surrounded by orthoclase-microperthite* (F), *in pyroxene-granulite; Ragedara* (×57). *See p. 595.*



[It is supposed that the three portions of garnet are remnants of a single individual.]

Type 2. Ragedara.—In two specimens of pyroxene-granulite associated with graphite-veins, the felspar is almost entirely orthoclase and the pyroxene is rather scarce, although the rocks are dark. The minerals are quartz, orthoclase-microperthite, garnet, biotite (scarce), hornblende (replacing pyroxene), sphene, magnetite,

apatite, and zircon. The structure is granulitic. The garnets are transparent and fresh. They show no trace of crystalline form, but have a much corroded appearance; in many cases the grains are deeply hollowed out so as to be crescent-shaped, in others two or three small grains near together appear to be the remnants of a larger grain (see fig. 1, p. 594). The garnets are more often surrounded by the microperthite than in contact with the abundant quartz. With the corroded garnets and the microperthite is associated the brown mica, which lies in the bays and hollows that appear to have been eaten out of the garnets (Pl. XXXIII, fig. 2).

TYPE 3. Dondra Head (the southernmost point of Ceylon).—Much crystalline rock in large boulder-masses is found on the shore. In one specimen the minerals are orthoclase-microperthite, quartz, plagioclase, garnet, hypersthene, hornblende, magnetite, apatite, and zircon. The dark minerals are arranged somewhat in parallel layers, and the quartz-grains are elongated in the same direction. A precisely similar rock is found on the little island near the shore, south of the rest-house at Matara.

Galle.—A very similar rock occurs in the quarry behind Galle town, associated with some decayed and schistose rocks among which a dark biotite-schist is found.

Colombo.—Irregular exposures of dark rock overlain by laterite are found near the site of the new graving-dock. The minerals are quartz (elongated grains), hypersthene, garnet, magnetite, and spinel. The magnetite is fairly abundant, and usually contains irregular patches and strips of resinous-looking, dark green, isotropic spinel. Occasionally very small portions of this green mineral seem to react on polarized light: this phenomenon may be due to local strain, or to the presence of chlorite.

Kandy.—There is an extensive exposure of very various gneissic rocks in the Mahaweli Gorge at Hakinda, near Kandy. A single specimen (on which a species of *Podostemon* was growing) is a fine-grained grey pyroxene-granulite composed of quartz, plagioclase, augite, and some graphite. A distinct parallel arrangement is noticeable, especially marked by the graphite and pyroxene: the appearance is suggestive of flow-structure.

Newera Eliya.—A greenish rock collected between Newera Eliya and the Rambodde Pass is a garnet-free pyroxene-granulite. The minerals are plagioclase (20° 23°, probably labradorite), quartz (elongated), pyroxene, apatite, ilmenite, apatite, and greenish decomposition-products.

Other pyroxene-granulites are described by Melzi [29] from Pidurutalagalla, and Diersche [30] from the quarry between Newera Eliya and Hakgala. They are also recorded by Dr. Diersche from Ragedara, Adam's Peak, and the Dimbula Estate, and by Melzi from Bandarawela (garnetiferous pyroxenite).

(2) Normal Granulites.

These and allied rocks are abundant in Ceylon. They are typically white or grey, and contain currant-red garnets; the texture is compact or saccharoidal, and traces of graphic structure are often recognizable. The quartz-grains do not contain lines of fluid-cavities, and the rocks seem igneous rather than metamorphic. The minerals include quartz (elongated grains), felspar (orthoclase- and microcline-microperthite and plagioclase), and garnet, with often also biotite, magnetite, ilmenite, apatite, and zircon. The microscopic structure is very granulitic: the minerals being much and confusedly interlocked, and the quartz-grains considerably elongated.

Kandy.—A characteristic white saccharoidal granulite with red garnets occurs in the quarry between the lake and the reservoir. It is largely used for road-metal.

Rocks collected at the far end of the reservoir contain conspicuous large garnets, sometimes in a white quartzose matrix, in other cases forming with biotite a biotite-schist. In the paler specimens the minerals are quartz, garnet, and plagioclase; the last-named contains curious tabular inclusions with their long axes nearly parallel to the twin lamellation: see Diersche [30] pl. vii, fig. 3.

Prof. Lacroix recorded garnetiferous leptynites from the Kandy district, and Dr. Diersche normal and zoisite-bearing granulites.

Ambakotte (near Kandy).—At the Gangapitiya moonstone-pits the coarsely-banded normal granulites are quarried by means of a short, sloping tunnel. The moonstone (orthoclase without microperthitic structure) occurs in rather large individuals in the granulite. Big pieces suitable for cutting are not very abundant, as the cleavage is well developed and the large individuals break into small fragments. The granulite, as seen under the microscope, consists of quartz (elongated and very irregular), and fine-grained, often micrographic; and very confused intergrowths of orthoclase-microperthite, plagioclase, and quartz. The elongated quartz-grains give to parts of the rock somewhat the appearance of a graphic granite. The appearances presented seem to suggest movement in a nearly consolidated magma, but might conceivably result from the recementing of a crushed quartz-felspar rock. The effect of movement in a viscous magma might be the production of the elongated quartz-grains, and the formation of confused intergrowths from the rest of the magma, the minerals not being able to grow in a well-individualized way after the remixing due to movement in the viscous mass. The orthoclase-grains are sometimes bordered by a peripheral, more transparent quartz-like zone extending irregularly into their interior, and the appearance is often very like that of Lacroix's figure [17] fig. 49, p. 300. Careful examination between crossed nicols, however, shows that the apparent quartz is here generally plagioclase, very faintly twinned, while in some cases it may be actually quartz. In the latter event the appearance is more conformable with the idea contained in the phrase

'quartz de corrosion' than is the case with the sharply-defined vermicular quartz often occurring in the felspars, where its presence is probably due to the contemporaneous intergrowth of the two minerals.

Galle.—A light-grey rock with scales of graphite, associated with the wollastonite-scapolite-bearing rocks, consists of microcline and some orthoclase-microperthite and quartz (elongated), and also very little sphene, augite, apatite, secondary calcite, and muscovite.

A vein, apparently intrusive in the same series, is very similar, but contains a little plagioclase and hornblende and has no graphite.

South of Galle Harbour a new path has been made from the shore to the plague-camp established on Buena Vista Hill, and near the top fresh specimens are obtainable from the blasted rock. The rock is greenish-grey, and shows a greasy lustre. The rather large felspars resemble those seen in laurvigite, but have no blue sheen. The minerals are orthoclase-microperthite and quartz, with also plagioclase and a very little pyroxene, ilmenite, zircon, and apatite. The structure is not granulitic.

Ambalangoda.—Immediately north of the little river is a small rock-exposure projecting from the sand, containing what was apparently a dark vein about 8 inches wide. A section of the 'junction of rock and vein' shows that the former is a quartz-felspar (chiefly plagioclase) rock with very scarce biotite, magnetite, apatite, and rhombic pyroxene. The quartz-grains are elongated. This granulitic rock appears uncrushed up to the 'junction,' where however, there is every appearance of shearing. The very minute biotites are arranged in a stringy way, so as to include lenticular areas of quartz and felspar. As one proceeds farther into the 'vein' the shearing becomes less evident, though for nearly $\frac{1}{2}$ inch included in the slide it has a crushed appearance, which the outer rock has not. The more abundant biotite chiefly distinguishes the dark 'vein' from the outer rock. It seems clear that an old line of shearing has been recemented. It is noteworthy that this is the only Ceylon rock that I collected wherein clear evidence of mechanical deformation appeared.

Ragedara.—Normal garnetiferous granulites were noticed at the graphite-mines, where they were also found by Dr. Diersche.

Kalawewa.—Following the bund past the P.W.D. bungalow, about $1\frac{1}{2}$ miles from it the road ultimately leaves the great reservoir. A greyish-green rock collected at this point resembles that from Buena Vista, Galle, consisting essentially of orthoclase-microperthite (Pl. XXXIII, fig. 5) and quartz, with some hornblende and very little plagioclase, augite (?), magnetite, and zircon. In this and the Buena-Vista rock the microperthitic structure is very clearly seen.

Anuradhapura.—A normal granulite without garnet occurs near the Newerawewa sluice, where the outflow runs under the road. A specimen collected on the Anuradhapura road, nearly 69 miles from Kandy, is a yellow rock with minute garnets: it is a normal granulite.

(3) Diorites.

These were noted at Ambalangoda and Kandy. They are dark rocks with a characteristic 'pepper-and-salt' appearance. The varieties include normal diorites, and quartz- and quartz-hypersthene-diorites. The structure is granular; where foliation is present the quartz-grains may be elongated. The hornblende is often partly derived from the pyroxene.

Ambalangoda.—The dark diorite here is apparently intrusive in gneissose rocks. It is well seen on the shore opposite the rest-house, where it is traversed by fine felspathic grains, and it occurs in a dyke-like manner in the quarry on the first little promontory south of the river, south of the rest-house. The minerals are hornblende and plagioclase (26° 29°, probably labradorite) with a little biotite, apatite, and zircon. Brown-stained and greenish decomposition-products are occasionally associated with undecayed fragments of a pyroxene, which they appear to represent. Quartz is absent: the rock is a normal diorite.

Kandy.—A dark-banded rock occurs in the quarry between the lake and the reservoir, associated with the more abundant white normal granulite. The foliation in the diorite is due to alternations of hornblendic with purely quartzose-felspathic bands. The minerals are plagioclase (20° 21°, probably labradorite), hornblende, quartz, scarce biotite, magnetite, apatite, and zircon, and also a little decayed pyroxene. The rock is a quartz-diorite.

A very dark diorite is seen in the quarry on the Pallekelle side of the ferry, below Kandy. The minerals are as in the last rock, but a considerable amount of hypersthene is present: the foliation also is similar. This rock is a quartz-hypersthene-diorite.

(4) Dolerites.

Ohiya.—A specimen from the railway-cutting near the first tunnel above Ohiya Station is a hornblende-biotite-dolerite, containing plagioclase (probably labradorite), hornblende, biotite, augite, hypersthene, magnetite, pyrite, apatite, and zircon. The alteration of the pale augite into dark hornblende, commencing along the cleavage-traces, is well seen.

Horton Plains.—A similar rock, collected about 1000 feet higher, near the Horton Plains rest-house, is a hornblende-hypersthene-dolerite, containing plagioclase (23° 24°), hornblende, augite, hypersthene, magnetite, and apatite.

(5) Gabbro.

Colombo.—Near the Battenberg Battery a dark rock, weathering into large spheroidal masses, has been recently exposed. It consists essentially of plagioclase (35° 36°, probably labradorite) and pyroxene (sea-green augite and pleochroic hypersthene); hornblende and biotite are abundant; magnetite, apatite, and zircon are also

present. The hornblende is partly derived from the pyroxene. This rock is a hornblende-gabbro. (See Pl. XXXIII, fig. 6.)

(6) Quartz-Norite.

A beautiful example of quartz-norite occurs not very far from Kurunegala, on the right-hand side of the Ragedara road, forming a rock known as Muttatugala, which has been quarried for road-metal. The rock is coarse-grained, and greenish-grey to brown. The hypersthene, plagioclase, and quartz are easily recognizable macroscopically; the only other minerals are magnetite and a grain or two of hornblende. The plagioclase (27° 29°, probably labradorite) has a blue sheen. The hypersthene occurs in large patches which may exceed 2 inches in diameter, or it may be more regularly distributed: the peripheral portions of the large patches may often be seen to enclose the felspar in an ophitic manner. Crystalline form is quite absent. In very thin sections the hypersthene is scarcely pleochroic, but in thicker cleavage-fragments a normal pleochroism is strongly marked. My friend, Mr. S. Hastings, has kindly analysed this pyroxene in duplicate, with the following results:—

	I. Per cent.	II. Per cent.
SiO_2	50·97	49·93
Al_2O_3	1·30	·15
FeO	27·21	29·61
MgO	20·87	21·22
	100·35	100·91

Specific gravity = 3·55

The ferrous oxide was weighed as ferric oxide and calculated into ferrous; the alumina is probably overestimated in the first analysis.

(7) Serpentine.

A dark-green decayed rock, found on the spoil-heap at Nilhene graphite-mine, is formed chiefly of serpentinous material. Much of this is derived from enstatite, the characteristic cleavage and straight extinction being occasionally distinguishable in less decayed nuclei. Other portions appear to have been derived from olivine. A few crystals of colourless augite and sphene also are present. It is noteworthy that, out of numerous specimens collected at Nilhene, this alone appears to be of the nature of a massive rock and not of a vein-product.

(8) Limestones.

White crystalline limestones occur in several localities, such as Hakgala, Talatuoya near Kandy, and between Matale and Dambulla, on the Anuradhapura road. The stairways at Sigiri are made of white limestone, often containing pale mica and prisms of blue apatite. At Anuradhapura it has been used in some cases for

statues. 'Cipolins' from the neighbourhood of Kandy were recorded by Prof. Lacroix.

Hakgala.—The 'limestone' is found on the Albion Estate, where it has been quarried to a slight extent. The rock is white and crystalline, its texture varying from somewhat coarsely crystalline to saccharoidal. It contains abundance of sky-blue apatite, and much white or pale greenish mica; the latter occurs most frequently in the joints, forming six-sided crystals, and is found also in the rock-mass. Under the microscope the rock is seen to consist largely of colourless monoclinic pyroxene (perhaps sahlite) with also apatite, analcite (?), and a little calcite and muscovite: the whole being very granular, and the constituent minerals often confusedly intergrown.

The pale mica has the optical characters of a biotite. Part of a fresh-looking crystal was supplied to Mr. Shepherd, F.I.C., for analysis, with the following result:—

SiO_2	40·72
Al_2O_3	26·38
Fe_2O_3	trace
MgO	14·27
K_2O	10·36
F	·78
Loss on ignition	7·63
Organic matter	trace
	100·14
O_2 replaceable by F	·33
	99·81

Specific gravity = 2·57

Talatuoya (near Kandy).—Much limestone is exposed on the 'Mica Estate.' The rock is white, with occasional prisms of blue apatite, flakes of white mica, or flakes of graphite. The white carbonate is probably dolomite, showing under the microscope little twinning and bright interference-colours.

Limestone exposed on the road between Talatuoya and Kandy is very coarsely crystalline, and without the accessory minerals.

(9) Microcline-Gneiss.

This rock occurs in the country north of Matale, and with other gneisses forms the solitary hills which suggested to Prof. Walther the term domoid gneiss. The rocks are well-banded. Their constituent minerals include microcline (as a rule slightly microperthitic), orthoclase-microperthite, quartz, plagioclase, and small quantities of pyroxene, hornblende, biotite, muscovite, pyrite, apatite, and zircon.

Dambulla.—A steep black rock rises not far from the village, with, near its summit, a series of Buddhist rock-temples. A

specimen was found to contain chiefly microcline and quartz, with also a little plagioclase, biotite, muscovite, and calcite.

Similar rocks with a little pyroxene and hornblende occur in the shallow road-metal quarry, by the roadside north of the village. Typical microcline-gneiss occurs near the fork in the road some miles north of Dambulla, and also near the new Sigiri rest-house, where the mineral-banding is very conspicuous.

Other exposures were noted on the Anuradhapura road at distances of $51\frac{1}{2}$, $52\frac{1}{4}$, and $72\frac{1}{4}$ miles from Kandy.

(10) Anorthosite-Gneiss.[1]

Certain gneisses found in Ceylon come under this head, inasmuch as the sole or dominant felspar is plagioclase.

Sigiri.—The imposing Sigiri rock is well known from an archæological point of view, and has been rendered accessible by Mr. Bell. It is a large rounded mass of gneiss, overhanging more or less on every side. The gneiss is conspicuously banded. Dark vertical surface-stains are evident, as is generally the case with the bare rocky slopes that occur in Ceylon. Thin slices show quartz and plagioclase, with more or less biotite, and a little secondary muscovite.

Colombo.—From quarries in the Madampitiya and College roads several specimens were obtained, and six microscope-sections prepared. The minerals are quartz, orthoclase, plagioclase, biotite, hypersthene, magnetite, apatite, and zircon. The term anorthosite-gneiss is applicable to those varieties which consist chiefly of quartz and plagioclase, with a little biotite and hypersthene. In specimens from the College-road quarry minute quantities of spinel are associated with the magnetite, as is the case in the rock from the site of the new graving-dock (p. 595).

Kalawewa.—A specimen from near the big sluice shows in a microscope-section plagioclase (17° 17°, probably oligoclase), quartz, hornblende, augite, biotite, magnetite, apatite, and sphene.

(11) Granite.

The curious 'animal-shaped' hills in the Kurunegala district were described by Dr. Diersche as granite. He says also that the columns of the Brazen Palace at Anuradhapura are hewn granite.

At Mahara, a large convict-quarry in the Colombo District, a great depth of rock is exposed; it is overlain by laterite. The rock is best described as a rather variable gneissose granite. It is sent in large quantities to Colombo, where it is crushed and mixed with cement, and moulded into large blocks, which are used in the construction of the new breakwater.

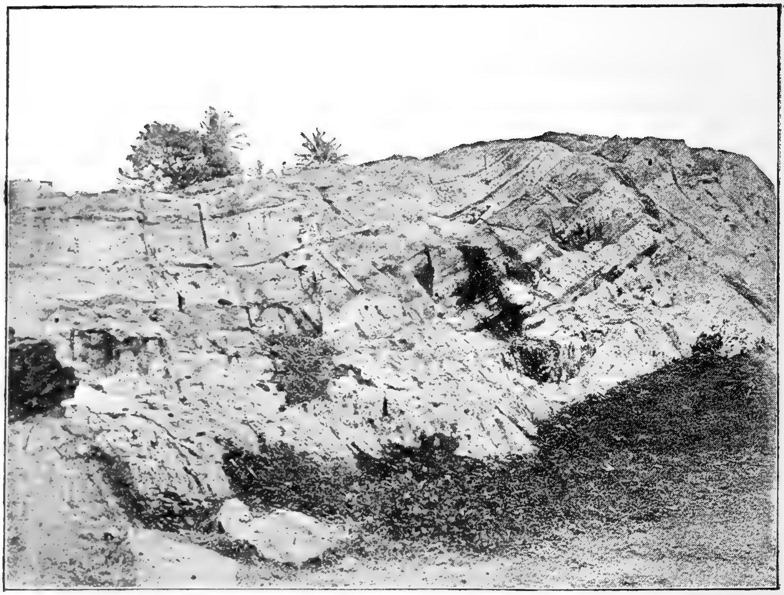
[1] The term gneiss is used for convenience, here and elsewhere, though it is perhaps hardly correct to speak of igneous rocks as gneisses.

(12) Pegmatite.

Veins of coarse pegmatite traversing other rocks seem rare in Ceylon. They were only seen in a quarry by the roadside between Wattegama and Pamvile.

Much of the rock exposed at Ambalangoda is pegmatitic in the true sense. Thus, in some cases, fairly large idiomorphic individuals of hornblende and orthoclase are embedded in a quartzose matrix. It appears that graphic granite is brought from Ambalangoda, but I did not find this rock, although traces of graphic structure are abundant.

Fig. 2.—*Section near the flagstaff, Galle Fort, showing mineral-banding in the scapolite- and wollastonite-bearing rocks.*



[Below the letter *A* in the figure a 2-foot rule is seen.]

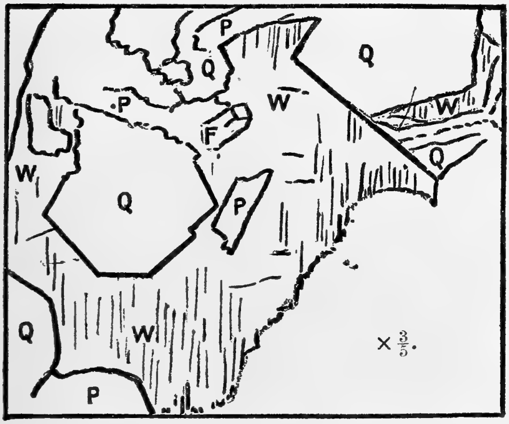
(13) Rocks of Unusual Composition.

Galle.—The rocks now to be described from Galle are peculiar in their petrological characters and mineral composition. They are specially marked by the presence of scapolite, wollastonite, and a green monoclinic pyroxene (spoken of as green augite, but probably in each case having a composition near that of manganhedenbergite —see analysis, p. 604). The conspicuous mineral-banding and the tendency in the wollastonite to mould itself on the other minerals are noteworthy. The peculiar conditions giving rise to rocks of

this kind are far from evident: it is important to notice that they closely resemble rocks from Nilhene, which appear to be vein-products.

A series of rock-exposures is found in the grassy area next the sea-wall of the fort, especially near the flagstaff. The rocks are of exceptional mineral composition, and mineral-banding is very conspicuous (see fig. 2, p. 602); the appearances resemble those which would result from movement in a non-homogeneous magma. A large specimen from the middle of the exposure seen in the figure, varies from a moderately coarse pegmatite to a finer-grained rock in which the separate minerals are scarcely recognizable macroscopically. The pegmatitic portion shows idiomorphic quartz, green pyroxene, and rarer orthoclase embedded in a large individual of wollastonite (fig. 3). The cleavage-faces of the wollastonite have a pearly lustre and a striated surface. It breaks up readily in a fibrous way, and in some of the flakes the emergence of two optic axes may be seen in convergent polarized light, the open axial plane being perpendicular to the elongation of the flakes. The optical character is negative. From the large ophitic individual material for analysis was obtained and supplied to Mr. Shepherd, F.I.C. The results of his duplicate analysis are as follows:—

Fig. 3.—*Ophitic plate of wollastonite* (W), *enclosing idiomorphic quartz* (Q), *pyroxene*, (P), *and felspar* (F).



	I.	II.
	Per cent.	Per cent.
SiO_2	51·28	54·59
CaO	45·55	40·85
Al_2O_3	2·01	1·77
FeO	1·34	·70
Loss on ignition	not est.	2·29
	100·18	100·20
Specific gravity =	2·76	2·78

These analyses correspond nearly to the formula $CaSiO_3$.

Two or three microscope-sections cut from different parts of this specimen are seen to contain green augite, orthoclase-microperthite, quartz, scapolite, sphene, and iron-ore in different proportions. The scapolite gives negative uniaxial interference-figures, and depolarizes vividly even in thin sections. Grey fibrous decomposition-products are often present.

A banded, dark rock, collected near by, contains scapolite, augite, quartz, wollastonite, sphene, graphite, pyrite, and calcite. Scapolite is very abundant, and may be recognized by its rectangular cleavage, straight extinction, and negative interference-figure. It is water-clear, but contains some minute lath-shaped opaque inclusions and needles of a transparent mineral arranged with their long axes parallel to the vertical axis of the scapolite. The wollastonite occurs in fairly large individuals, which are evidently moulded on the other minerals. It is colourless, and has a moderately high refractive index, but rather weak double refraction. Its biaxial character can be ascertained: the open axial plane is at right angles to the parallel cleavage-cracks. The wollastonite has been sometimes replaced by a quartz-calcite mosaic which occurs in some small areas between the other minerals, often associated with a residual fragment of wollastonite. Two portions of wollastonite extinguishing simultaneously may be thus separated by a fine-grained quartz-calcite mosaic: in some cases no wollastonite is left, in others no trace of alteration is visible in it.

An even, but not fine-grained, green-and-white rock from the same locality contains the usual pale green 'augite,' orthoclase- and microcline (?)-microperthite, scapolite, sphene, zircon (?), apatite, and graphite. A considerable quantity of this rock was crushed and passed through a mesh with 30 holes to the square inch, but was retained by one with 60. The grains thus obtained were not composite. The pyroxene and sphene were separated by means of cadmium borotungstate, and the pyroxene was then picked out with a camel's-hair brush. More than 3 grammes of perfectly pure light green pyroxene being thus obtained was supplied to Mr. Shepherd for analysis, with the following result:—

	Per cent.
SiO_2	50·91
CaO	24·41
MgO	·58
Al_2O_3	1·78
MnO	2·64
FeO	19·91
	100·23

Specific gravity = 3·377

This composition corresponds almost exactly with that of manganhedenbergite, to which species the pyroxene must be referred. Neglecting the alumina and a little of the silica, the formula $CaFe(SiO_3)_2$ is obtained.

Nilhene graphite-mine.—Specimens from this locality are very similar in petrological characters to those described from Galle. They differ chiefly from the Galle rocks in being associated with vein-graphite; in the presence of a micrographic intergrowth of quartz and calcite in some cases; and in the greater abundance of calcite.

A specimen associated with a vein of graphite (see p. 610) may be described in detail. The minerals are quartz, calcite, augite, scapolite, and sphene. The augite is of the usual pale green, with extinction-angles ranging up to 44°: the smaller individuals join in a pegmatitic structure with the quartz and calcite; but with larger grains this is only true of their border. The intergrowth of quartz and calcite is such, that in a small area the quartz and calcite severally extinguish uniformly (Pl. XXXIII, fig. 1). In other parts of the slide there is merely a quartz-calcite mosaic. The scapolite is recognized by its rectangular cleavage and negative uniaxial interference-figure, etc.

In other specimens the mineral associations are:—

(1) Quartz, calcite, and graphite (scattered);
(2) Augite, scapolite, orthoclase, wollastonite, graphite, sphene, iron-ore, and calcite;
(3) Orthoclase, augite, sphene, magnetite, graphite, calcite, quartz: the quartz and calcite forming a mosaic in small patches, probably replacing wollastonite;
(4) Orthoclase and scapolite;
(5) Quartz, orthoclase, and graphite.

In many of these cases a small quantity of an undetermined mineral is present. It occurs in sheaf-like aggregates or in radiating flakes, in connexion with the nests of stringy and dusty graphite. Cleavage parallel to the length of the flakes is well-marked, less common is one perpendicular thereto. Extinction is parallel to the principal cleavage. The mineral is colourless, and has a low refractive index, bright interference-colours, and strong double refraction. It does not appear to be muscovite.

These rocks, some of which, as I said, are associated with vein-graphite, are very probably themselves rather of the nature of vein-products (see p. 610).

Ambakotte (near Kandy).—At the Gangapitiya moonstone-pits occur, besides the normal granulite, some curious banded or nodular rocks. Some specimens show straight, or more or less concentric, zones of grey, dark green, and white rock. The grey inner part seems to consist almost entirely of grey granular augite, rarely showing cleavage. The succeeding green band (reaching about $\frac{1}{2}$ inch in width) contains augite, plagioclase, spinel, and an abundant pleochroic undetermined mineral, the two last-mentioned giving the green colour. The undetermined mineral is pale greenish-blue by transmitted ordinary light, and is strongly pleochroic from pale green to sky-blue: multiple twinning is conspicuous; the appearances suggest a ferromagnesian mineral. The spinel is granular, pale green, and has a very rough surface. Dusky

inclusions may occur in definite planes. The grains are not attacked by drops of hydrofluoric acid placed on the slide. The light-coloured succeeding portion of the rock consists chiefly of quartz and plagioclase.[1]

(14) Quartz-Calcite Micropegmatite.

A graphic intergrowth of quartz and calcite has been described above (p. 605 & Pl. XXXIII, fig. 1). I believe that such an intergrowth has not been previously observed. Graphic intergrowths, probably resulting from the simultaneous intergrowth of two or more minerals forming an eutectic mixture,[2] are well known to occur in rocks which have consolidated from igneous fusion. It is hardly probable, however, that in the present case the quartz and calcite have consolidated from igneous fusion. It is easier to suppose that we are dealing with a vein-product, the result of a kind of solfataric action, rather than with a true magma-rock. Quartz and calcite are common vein-products, and often occur together in an ordinary way. It seems to me possible that conditions analogous to those found in consolidating igneous magmas might be produced in connexion with the formation of vein-products. In this way a micrographic intergrowth of quartz and calcite might be produced.

(15) On Centric Structures in Pyroxene-Granulites.

Intergrowths of pyroxene and plagioclase from Pidurutalagalla, Ragedara, etc. have been described above (pp. 593, 594 & Pl. XXXIII, figs. 3 & 4). Similar intergrowths, on a larger scale, of pyroxene, oligoclase, and quartz, and of pyroxene and oligoclase, have been recorded by Lacroix [17] from Salem and Ceylon. He describes from Salem a micropegmatite of amphibole and orthoclase forming a corona 1 cm. thick, surrounding garnets of the size of a man's fist.

The radiating pyroxene-plagioclase intergrowths of the Pidurutalagalla rocks may be considered first. Here the 'straits' of felspar, separating magnetite and garnet which would otherwise fit together, have also to be explained. The following is a suggested theory for this case:—Magnetite and garnet were formed early, the garnet often enclosing the magnetite. Pyroxene, and then felspar followed; in parts of the rock not containing garnets they were able to crystallize without interfering one with the other. Some change in the physical conditions occurring at this stage caused the corrosion of the garnets, and perhaps partly also of the pyroxene, by the viscous felspathic magma. Thus channels were eaten out between the garnet and magnetite, and to some extent between the garnet

[1] I hope to be able to obtain more material, and isolate the undetermined mineral. This has not yet been possible, owing to its fine grain and the small amount of material available.

[2] Fr. Becke, 'Die Gneiss-Formation des nieder-œsterreichischen Waldviertels' Tscherm. Min. u. Petr. Mitth. vol. iv (1882) p. 406; Teall, 'British Petrography' 1888, p. 401; Bonney, 'On a Contact-structure in the Syenite of Bradgate Forest' Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 101.

and pyroxene. The constitution of the viscous magma would be altered by the absorption of garnet-material, which would also tend to increase the viscosity in the neighbourhood of the garnets. So that in the area between the now corroded garnets there was present a pasty felspathic magma containing in solution the remnants of the pyroxene-elements, with some derived from the corroded garnets. As cooling proceeded some pyroxene was added to the original grains (the appearances tend to suggest this), and the remaining narrow strips of magma consolidated as an intergrowth of pyroxene and felspar, the felspar forming ophitic plates and the garnets serving as a point of attachment for the root-like fingers of pyroxene. Thus, in the end, we have slightly more pyroxene present than if the garnets had not been corroded, for portions of the magma which would have consolidated as pure felspar may, with the addition of magnesia, iron, and calcium which a pyrope would supply, have actually formed a pyroxene-felspar intergrowth. Intergrowths of plagioclase, pyroxene, biotite, and magnetite in connexion with garnets occurring in a Ragedara rock are somewhat similar; and indications of the same structure are found in a granulite from Talatuoya. These radiating coronas differ from those described by Prof. Lacroix in the root-like form of the pyroxene.

In the pyroxene-granulite of Ragedara, associated with the graphite (see p. 594, text-fig. 1, & Pl. XXXIII, fig. 2), somewhat similar phenomena seem to have occurred; but here the prevailing felspar is orthoclase, and accordingly the result of the corrosion of the garnets has been the formation of brown mica. Probably the garnets appeared early in the history of the rock, and served as nuclei round which the felspathic material tended to collect: subsequent change in the physical conditions caused the corrosion of the garnets, without sufficient movement taking place in the viscous magma to separate the products of corrosion from the garnets.

The occurrence of centric and granulitic structures in pyroxene-granulites was noted by Dr. Becke; and it probably has some special significance in connexion with their origin which is not yet fully understood.

The contemporaneous formation, by the interaction of two minerals, of a third mineral or mineral variety is comparable with the fact that in any ordinary rock in which, for example, hornblende, biotite, and felspar are found, the biotite is often intimately associated with the hornblende. This probably results from a slight mixture of materials at the edge of the newly-formed hornblende-crystals, taking place as the magma consolidates.[1]

(16) Microperthite.

The orthoclase of Ceylon rocks is scarcely ever without the fibrous microperthitic structure. In many cases it can be seen, even

[1] [See Parsons, 'The Development of Brown Mica from Augite by Reaction with Felspathic Material' Geol. Mag. 1900, p. 316.—July 15th, 1900.]

with a low power in a thin section, that this appearance is due to the presence of parallel rods and spindles (of plagioclase). If ordinary convergent light is used, and all but the central rays are cut off by a diaphragm, the plagioclase stands out very clearly against the orthoclase by reason of its higher refractive index. Between crossed nicols the structure becomes still more evident. The plagioclase-strips are usually spindle-shaped and pointed at both ends, more rarely they are lamellar, or irregular. In hand-specimens of the rocks containing them, these felspars appear greenish-grey with a rather greasy look, resembling the felspars of the well-known rock from Laurvig, but without their blue sheen.

The structure is best seen in sections parallel with M $(0 1 0, \infty P \breve{\infty})$. The orthoclase-cleavage on P $(0 0 1, OP)$ is clearly marked, and crosses the less evident cleavage on $1 0 0 (\infty P \bar{\infty})$ at about 110°. The plagioclase-spindles are seen to have their long axes parallel to the latter cleavage, that is, they run parallel to the vertical axis of the orthoclase.[1] A basal cleavage is observed also in the plagioclase, and it is parallel to, or continuous with, that of the orthoclase (see Pl. XXXIII, fig. 5). The spindles may be of uniform size, or there may be many smaller with larger individuals among them. They may be few and scattered, or so numerous as to exceed the orthoclase in amount.

The homogeneous-looking orthoclase background gives rather high extinction-angles (up to 8°) from the cleavage parallel with P $(0 0 1, OP)$. The extinction-angle of the plagioclase-spindles is not so easy to determine. Cleavage-flakes or sections for measurement must be very thin and of uniform thickness, otherwise the higher refractive index of the plagioclase renders it difficult to be sure of the exact position of extinction. In a suitable flake from the Kalawewa rock (see p. 597), the following data were determined:—The cleavage-flake is parallel with M $(0 1 0, \infty P \breve{\infty})$ and is bounded above and below by the basal cleavage, which makes an angle of 108° with the fine striation representing the orthopinacoidal cleavage of the orthoclase, to which the plagioclase-strips are parallel. The extinction-angle of the orthoclase from the trace of OP was 8°, that of the plagioclase from the same trace (that is, on $\infty P \breve{\infty}$) was 14°.

In a specimen from the Buena-Vista rock (p. 597) the orthoclase cleavage-angle was 112°, the orthoclase extinction-angle from the trace of OP 7°, and the plagioclase extinction-angle from the same trace 14°. These results agree with those of Dr. Diersche [30] p. 250, who says:

> 'extinction-angles of 13° to 17° in relation to the trace of OP were measured in the lamellæ, showing their identity with an albite or labradorite;'

that is, the extinction on M $(0 1 0, \infty P \breve{\infty})$ is from 13° to 17°, leaving the ambiguity between albite and labradorite.

He says, however, that in basal sections where the orthoclase has

[1] In the Ragedara pyroxene-granulite the intergrowth seems to be a little more complicated.

straight extinction with regard to the edge P/M (that is, the trace of the clinopinacoidal cleavage), the extinction of the lamellæ does not differ from that of the orthoclase more than from 2° to 4°. That is, for the plagioclase-lamellæ the extinction on P (0 0 1, OP) is from 2° to 4°. This fact, correlated with the extinction on M (0 1 0, ∞ P $\breve{\infty}$) indicates that the lamellæ probably belong to an 'oligoclase-albite' and not a labradorite. Accordingly the plagioclase-spindles are spoken of in this paper as albite-lamellæ, though it is very possible that the felspar is not the same in every case.

Microcline, where it occurs, is found to contain similar albite-spindles, forming microcline-microperthite. The microcline is easily distinguished from orthoclase in the usual way.

IV. The Graphite: its Mode of Occurrence and Origin.

Graphite is Ceylon's most important mineral product. Its export began before 1830, and now amounts to about 18,000 tons yearly. The Ceylon graphite is remarkably pure, and it is often found in large masses free from other minerals: specimens weighing more than 5 cwt. have been thus obtained. An excellent account of the Ceylon trade in graphite has been given by Mr. A. M. Ferguson [12]. F. von Sandberger [14] described the Ceylon graphite mineralogically; and it has been used among others by W. Luzi[1] in his chemical researches on the mineral.

While graphite is not unfrequently found in the igneous rocks of Ceylon in the form of small scales and strings, it is as yet only where it occurs as a vein-stone that it has been worked commercially.

Its singular mode of occurrence in branching-veins was first noted by Prof. Walther [18] on the eastern banks of the Kaluganga, about six hours' sail from Kalutara. Here, from the

'light red laterite exposed in the quarry to a depth of 12 metres a system of much-branched veins of black graphite stands out most conspicuously.'

The laterite-matrix was free from graphite, which occurred only in the veins. He supposes that fissures originated in the unweathered gneiss by dislocations, and were filled up by graphite:

'When at a later period the gneiss decomposed into laterite, the carbon-filled veins remained unaltered and occur in the laterite to-day, a telling proof that this rock was formed *in situ* and has not been remanié.'

The occurrence of graphite at Ragedara as a vein-stone was noted by Prof. Zirkel and Dr. Diersche; I have also found it in the Baddegama district.

The vein-graphite shows coarse platy, or stem- or needle-like, forms arranged at right-angles to the edges of the veins. Sometimes other layers of graphite-elements follow, inclined at a slightly different angle, representing probably a second period of deposition. Graphite may occur also in radially arranged groups of crystal-like

[1] Berichte d. Deutsch. Chem. Gesellsch. vol. xxiv (1891) p. 4085 & vol. xxv (1892) pp. 214, 1378.

forms in quartz-veins. It is curious that the flakes and scales of graphite often show on their surface a system of lines, perhaps representing cleavage-cracks, which intersect at angles approximating to 60°, 90°, and 120°.[1]

The graphite-veins contain numerous inclusions. Dr. Diersche mentions quartz, iron-ore, orthoclase, hornblende, mica, apatite, calcite, and especially rock-fragments, as occurring included in the graphite of Ragedara, where the matrix consists of normal and pyroxene-granulites. The rock-fragments included specimens of these rocks, also a granite and a quartz-felspar-garnet-rock with muscovite, and very large zircons and apatites. None of these rocks seems very far removed from possible varieties of the matrix. Hence we may hope to gather some evidence concerning the origin of graphite as a vein-stone from the relations existing between the graphite-veins, the contiguous matrix, and the included fragments.

Two specimens from Ragedara show these relations well. The first, a greenish pyroxene-granulite, is surrounded on three sides by a graphite-vein varying in thickness from 2 to 20 mm. The stalky graphite is arranged compactly, perpendicular to the surface of the rock. A thin section has been made, including about $\frac{1}{4}$ inch of graphite and rather more than $\frac{1}{2}$ inch of the rock. Held up to the light, it shows a sharp division between the opaque graphite and the semitransparent rock. Under the microscope, it appears that graphite is absent from the greater part of the rock, but that as one approaches the junction between rock and vein, the former becomes thickly speckled with dusky graphite, and plates and scales of graphite appear inclined at various angles. The rock is perhaps rather less well preserved in this narrow zone next the vein itself, suggesting infiltration.

In another specimen from the same locality the relations between rock and graphite-vein are clearly seen on a larger scale (fig. 4, p. 611). The photograph represents a smooth surface taken by reflected light, so that the graphite appears white, the rock mottled grey. The vein is of flaky graphite, the veins being as usual perpendicular to the rock-surface: about $\frac{3}{4}$ inch of graphite and $2\frac{1}{2}$ inches of rock are seen. For about $\frac{1}{4}$ inch from the vein the rock is impregnated with scales and flakes of graphite, some of the flakes occupying tiny cracks in the rock. This graphite-bearing zone looks rather less well preserved than the rest of the rock, which is compact and hard and contains no graphite.

Some specimens from Nilhene graphite-mine are slightly different. Here the rock on or in which the graphite is found is probably a vein-product (see p. 605). From two specimens (one of which has an external graphite-vein of the usual type, the other having two or three veins running through it) thin slices have been prepared. The rock-portion of the first specimen consists of quartz, calcite, augite, scapolite, and sphene. There is a sharp junction between it and the graphite, none of the latter being present in the

[1] Diersche [30] pl. vii, fig. 5 & p. 277; Rauff [25].

former. The vein itself is almost entirely made up of plates of graphite, which in the slice are generally perpendicular, with occasional narrow interspaces occupied by a zeolite.

Fig. 4.—*Junction of pyroxene-granulite [below] and graphite-vein [above]; Ragedara.* ($\times \frac{6}{5}$.)

In the other specimen, a graphite-vein $\frac{3}{8}$ inch wide is shown, and much graphite is scattered through the rock, so as to form a second, more irregular vein. A thin section shows much scaly graphite in a rock composed of calcite or quartz-calcite mosaic or micropegmatite. Where part of a vein is included in the section, the graphite-scales in it are parallel and closely set. In other parts of the slide the graphite is irregularly arranged. A zeolite is sometimes found between the scales in small quantity.

These Nilhene specimens differ from those found at Ragedara, in that the graphite-bearing rock is not an ordinary igneous rock as at that locality, but more probably a vein-product whose formation was contemporaneous with the deposition of the graphite.

The graphite mined at Mawatakelle and Deldahawatte in the same district, and at Godaduwa near Galle, I believe also occurs in veins.

We see, then, that the Ceylon graphite occurs chiefly in this way, and not in beds or lenticular streaks. When, however, it occurs as a rock-forming mineral (as, for example, in a specimen from Hakinda described on p. 595), it is present in small specks and scales, scattered through an igneous rock in quantities too small to repay the cost of working. In these cases it may be supposed to have consolidated from igneous fusion, bearing in mind the well-known occurrence of graphite as a furnace-product, and in meteorites.

It seems impossible to regard the vein-graphite as the highly metamorphosed remains of an ancient flora or fauna. The high melting-point of graphite and other considerations make it unlikely that the veins arose as dyke-like intrusions of molten graphite. Prof. Moissan[1] suggests that graphite may have crystallized out of an iron-magma, the iron having been subsequently removed chemically, but here no traces have been found of the immense quantity of iron that would be required for this process. Moreover, the included rock-fragments and the portions of the matrix next the veins would have been considerably altered by the high temperature required. It seems likely that the formation of these graphite-veins has not been associated with very extreme temperature at the point of deposition of the graphite.

Dr. Diersche [30] p. 287 suggests that the graphite may have been introduced in liquid hydrocarbons (such as petroleum, naphtha, or asphalt) which were reduced *in situ*. These liquids, rich in carbon, might have been introduced either from above or below.

Slightly different is the sublimation-theory of Prof. Walther [18], who refers to the occurrence of a graphite-like substance which is deposited in the flues of gas-works. He supposes, not that the carbon itself was sublimed, but that it was deposited in the veins from sublimed hydrocarbons.

Two hypotheses thus seem to be plausible, both involving the existence of suitable hydrocarbons: (i) the liquid theory of Diersche; and (ii) the gaseous theory of Walther. Each may be right in different cases, and neither presents any insuperable difficulty. The association of graphite, quartz, and calcite at Nilhene is, I think, in favour of the liquid theory; so too, perhaps, the slight impregnation of included rocks noticed at Ragedara.

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VI. SUMMARY.

Ceylon is surrounded by raised beaches, and has been elevated in recent geological times; fluviatile deposits also occur. The gems for which the island is famous are obtained from gravels in the Ratnapura district. With the exception of these quite recent deposits, the island probably consists entirely of ancient crystalline rocks, which may be considered Archæan in the absence of any evidence to the contrary.

Pyroxene-granulites are widespread and characteristic; their mineral composition is rather various. Certain structures in connexion with garnets are very characteristic of some types; they appear to result from the corrosion of the garnets by the magma. Normal granulites are also abundant; they are typically white or grey, and contain currant-red garnets. The granulitic structure and much elongated quartz-grains are characteristic. Microcline-gneiss, sometimes with hornblende, occurs in steep dome-like hills, originating the term domoid gneiss employed by Prof. Walther. Anorthosite-gneiss, gneissic granite, and pegmatite are also found, the latter occurring in veins, but very rarely. Other rocks include dark diorites and hornblende-gabbro. A quartz-norite containing large individuals of hypersthene occurs near Kurunegala. The white crystalline limestones often contain pale mica and blue apatite; in some, colourless pyroxene is very abundant.

Banded scapolite and wollastonite-bearing rocks are found at Galle. Certain rocks similar to these, but apparently vein-products, are also described; these contain in some cases quartz and calcite micrographically intergrown.

Graphite occurs chiefly in branching-veins in igneous rocks, which at Ragedara are granulites and pyroxene-granulites. The relations to the matrix are described, and are held to favour the idea of the deposition of the mineral as a sublimation-product (Walther), or from the decomposition of liquid hydrocarbons (Diersche). Chemical analyses of several minerals, including manganhedenbergite, are given.

EXPLANATION OF PLATE XXXIII.

[Photographs taken by ordinary light, except fig. 1.]

Fig. 1. Quartz-calcite-micropegmatite from Nilhene graphite-mine. ×33. Taken between crossed nicols. (See pp. 605, 606.)

2. Pyroxene-granulite from Ragedara. × 15.
This shows garnet, corroded and surrounded by orthoclase-microperthite, and intimately associated with brown mica. (See p. 594 & text-fig. 1.)

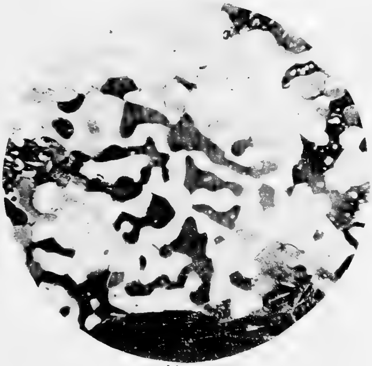
3. Pyroxene-granulite from Pidurutalagalla (Newera Eliya). × 15.
This shows garnets with fringes of pyroxene-plagioclase intergrowth (as in fig. 4) on one side; the garnets on their other side are in contact with the augite. A second generation of iron-ore is associated with the pyroxene-fingers. (See pp. 593, 606.)

4. Pyroxene-granulite from Pidurutalagalla (Newera Eliya). × 15.
The black portions are magnetite; they are separated by narrow strips of plagioclase from the garnet which has fringes of pyroxene-fingers projecting into the plagioclase; in the upper middle part of the figure a whorl of radiating pyroxene-fingers has for its centre a very small (residual) fragment of garnet. The remaining portions are chiefly pyroxene (augite). (See pp. 593, 606.)

5. Orthoclase-microperthite from Kalawewa. × 24.
The right-hand crystal shows the cleavage parallel to OP in both felspars. (See pp. 597, 608.)

6. Hornblende-gabbro from the Battenberg Battery, Colombo. × 13. (See p. 598.)

1.

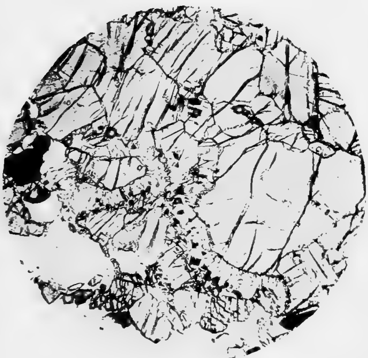


X 33.

2.

X 15.

3.

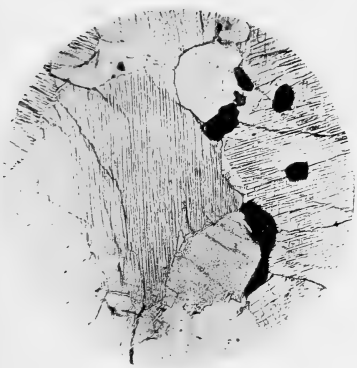


X 15.

4.

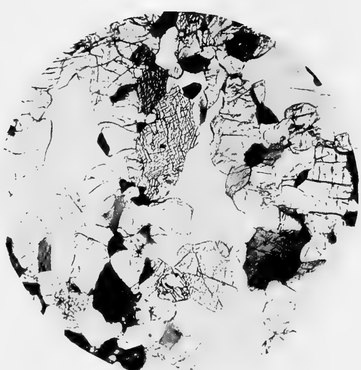
X 15.

5.



X 24.

6.



X 13.

Ceylon Rocks.

A. K. Coomara Swamy photo.

Discussion.

Prof. Bonney expressed his sense of the importance of this paper, on which he knew that the Author had expended great labour. It was interesting to find so great a mass of ancient crystalline rocks practically unaffected by pressure. The relations of the garnets, felspar, and pyroxene were most interesting and suggestive, and so, too, was the mode of occurrence of the graphite. He thought the paper also very valuable as illustrating the formation of a root-like graphic structure, which he thought implied crystallization under obstruction, while the ordinary rectilinear 'graphic' structure (to which the name was originally given) implied that one of the two minerals was not resisted by the other.

Dr. J. W. Evans referred to the resemblance between the rocks described in the paper and those of Southern India, of which Ceylon was geologically an integral part. Towards the south of the Indian peninsula the ancient sedimentary rocks disappeared, though the widely-extended granitoid gneiss still continued. The most remarkable fact, however, was the extraordinary development of the charnockite-series of Mr. Holland, which appeared to be identical with the present Author's pyroxene-granulites. These formed the lofty mountain-masses of the Nilgiris and Annamallais, and were, it seemed, the chief feature of the most elevated regions of Ceylon. Graphite also occurred in Southern India, not only in dykes in Travancore, but in flakes in holocrystalline igneous rocks both in Mysore and in British India.

The President also spoke.

The Author stated, in reply to Dr. Evans, that small flakes of disseminated graphite occurred in several of the igneous rocks of Ceylon. He distinguished between the graphite occurring thus as a subordinate rock-forming mineral, and the vein-graphite which had been deposited after the consolidation of the rocks in which it was found. In conclusion he heartily thanked the Fellows for the very kind way in which they had received his paper.

32. Fossils *in the* Oxford University Museum, IV: Notes *on* some undescribed Trilobites. By H. H. Thomas, Esq., B.A., F.G.S. (Read June 20th, 1900.)

[Plates XXXIV & XXXV.]

In the course of arrangement of the Trilobites in the Oxford University Museum, a few forms came under notice which might be considered worthy of description. They are two species of *Dalmania* from the Wenlock Shales, and one of *Olenus* from the Shineton Shales.

Phacops (Dalmania) coronatus, sp. nov. (Pl. XXXV, figs. 1–4.)

This species does not attain any considerable size, its total length being from $\frac{3}{8}$ to $\frac{5}{8}$ inch, while the ratio of its greatest breadth to length exclusive of the caudal spine is as 3 : 5.

The head-shield is semicircular and moderately convex, the genal angles being produced posteriorly into two long spines extending to the sixth thoracic segment. The external border is a flattened margin, narrowing in front of the glabella, and produced on its external edge into a series of spines, seemingly sixteen in number, symmetrically arranged. They are more or less equidistant one from the other and are of the same length, excepting those two that are immediately in front of the eyes, which seem to be about twice the length of the others.

The glabella is coarsely tubercular with smaller granules interspersed, and it widens anteriorly to more than one-third of the width of the head-shield. The forehead-lobe is more or less rhomboidal in outline, its width however being greater than its length, the latter being equal to half that of the total glabella. The inferior lobes diminish in size posteriorly, being separated by deep furrows which do not pass across the glabella, but are interrupted by a well-marked ridge running back from the frontal lobe to the posterior border.

The axial and neck-furrows are deep, while the axial part of the posterior border is furnished with a large central tubercle.

The facial suture circumscribes the glabella at its anterior margin, falling with an inward curve to the eye, and then arching upward and outward from the lower angle of the same, cuts the lateral border. The eyes are large and sharply curved, extending from the basal furrow of the glabella to the middle of the anterior inferior lobe. In no one of the specimens can the facets, however, be seen.

The thorax consists, as usual, of eleven segments, the axis being but moderately convex. The pleuræ are truncated and grooved, their fulcra being so situated that the inner part of the

pleura bears to the outer the ratio of 5 to 4. The inner part is straight and flat, while the outer curves downward and backward.

The second and fifth segments bear two small tubercles near the centre of the axis, while the first, sixth, and seventh bear large tubercles on the axis near the junction with the pleuræ.

Some of the pleuræ bear two small tubercles on the anterior side of the groove, near the centre of that part lying between the fulcrum and the axis. The pleuræ of the sixth and fifth segments, on the other hand, bear only one large tubercle on the posterior side of the groove—the former close to the axis, and the latter midway between the fulcrum and axis.

From the examination of all the specimens at my disposal, I infer that the ornamentation (as might be expected) is not a constant feature.

The pygidium is almost an isosceles right-angled triangle, the right-angle being produced into a long caudal spine equal in length to, or slightly longer than, the axis of the pygidium. The margin is entire, and formed of a smooth and more or less flattened border. The axis bears traces of thirteen segments.

Horizon and Locality.—All the specimens come from the Wenlock Shales, and were collected by the late Dr. Grindrod during the excavations made through the shale for the Malvern Tunnel. These specimens formed part of the Grindrod Collection.

Affinities.—This species bears a strong resemblance to, and is undoubtedly allied to, certain varieties of *Phacops* (*Dalmania*) *caudatus*, especially those more nearly approaching *Ph. longicaudatus.* But the differences are so well-marked as to preclude the possibility of its being the young of that species. First the spines round the head have, so far as I know, never been observed in any other species of *Dalmania*, or at any rate in the species of the *caudatus*-group. Again, the height of the head-shield and the distance between the eyes are both larger in proportion, being in the ratio of 13 to 11. The surface-ornamentation is apparently of a more severe type than one would expect in a young specimen; also the presence of a caudal spine of such dimensions seems to be a distinctive character.

Its nearest ally appears to be *Phacops* (*Dalmania*) *nexilis*, Salter's *Ph.* (*Odontocheile*) *caudatus*, var. γ.

Phacops (*Dalmania*) *nobilis*, sp. nov. (Pl. XXXIV, figs. 1–3.)

This species seems to have attained a considerable size. Its total length is about $2\frac{1}{2}$ to 3 inches in what is apparently an adult form.

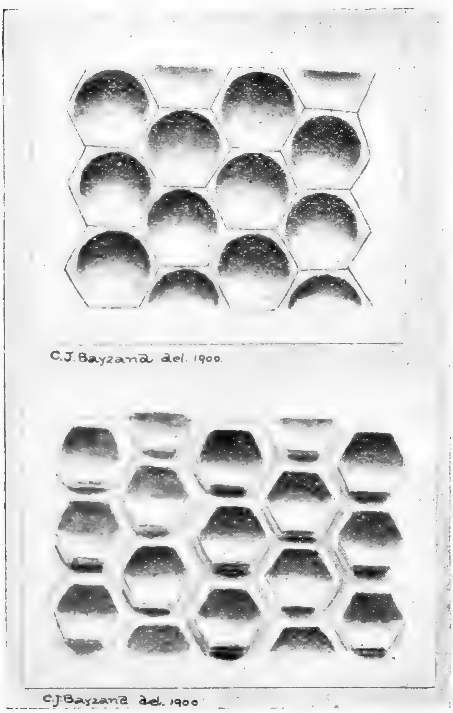
The head-shield is semicircular in outline, and moderately convex: the whole surface being tubercular, with a tendency to become spinose. The tubercles are not round, but elongated parallel to the axis. As regards the lobes of the glabella, the frontal is almost circular in outline. Behind it occur the axillary lobes, three in number. The glabellar furrows do not pass across the glabella, but are interrupted in the middle of their course by a well-marked ridge.

The external border consists of a flattened margin becoming obsolete in front of the glabella, and produced posteriorly into two long genal spines reaching as far as the sixth thoracic segment.

The facial suture circumscribes the glabella or rather the frontal lobe of the glabella, and from the lower angle of the eye it passes upward close to the eye for about one-third of its facetted surface, and then bends outward and upward to cut the lateral border of the head-shield. The eyes are large, and extend from the base of the frontal lobe of the glabella to the middle of the posterior lobe; they are strongly curved, and very prominent. Owing to the removal of the test by solution, I was able to obtain casts of the internal and external surfaces of the eye. It is seen that on the outer side the lenses have a greater area than they have on the inner. Their shape, therefore, is that of a truncated cone, with the base outward. (See the appended figure.)

The thorax consists of eleven segments. The axis is very convex, while the pleuræ are not much bent. Their fulcra occupy a point about two-thirds of the total distance from the axis. The pleuræ and the axis bear ornamentation similar to that of the head-shield, as also does the pygidium.

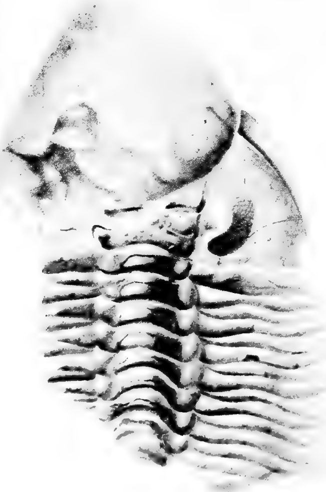
Casts of the internal and external surfaces of the eye of Dalmania nobilis *(greatly enlarged).*



The pygidium has the shape of an obtuse-angled isosceles triangle. There are from nine to eleven segments, and the axis is decidedly convex. The border is flattened, wide and rounded, not terminated by a caudal spine (as is the case in many other species of this genus).

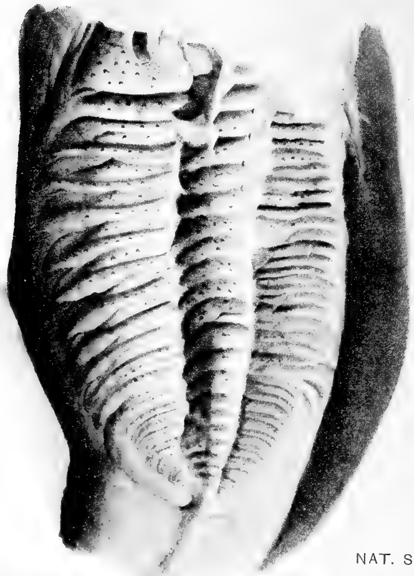
The specimen here described belongs to the Grindrod Collection, and came from the Wenlock Shales of Builth (Brecknockshire).

1.



Nat. size.

2.



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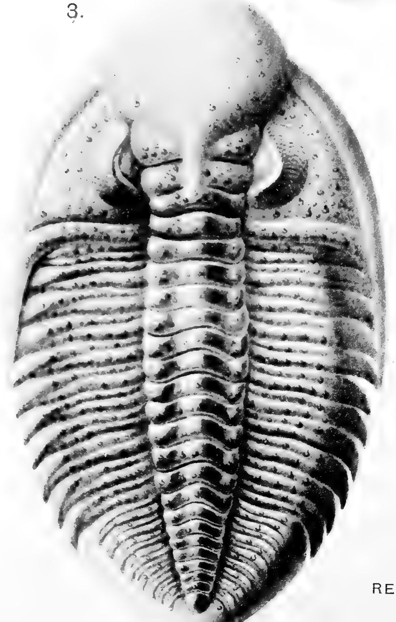
3.

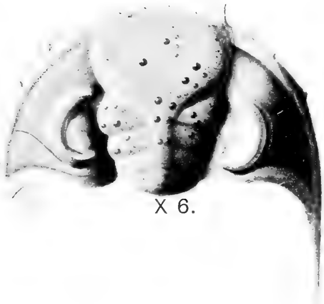


Restoration.

Dalmania Nobilis.

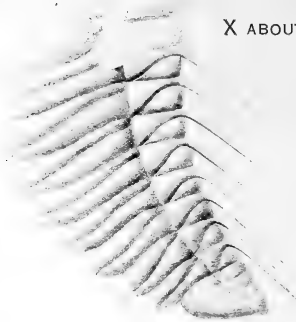
C. J. Bayzand del.

1.



X 6.

5.



X ABOUT 4.

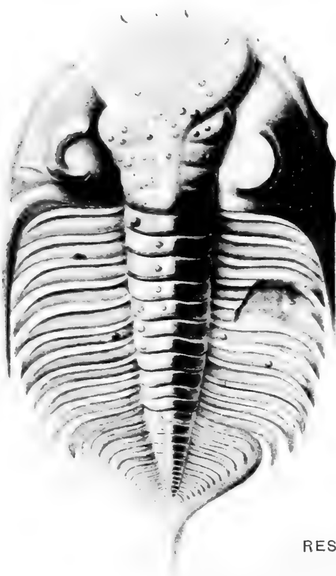
6.

X ABOUT 6.

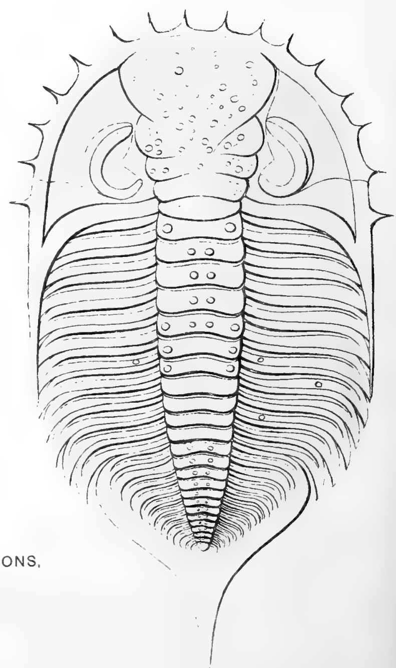
2.

X 6.

3.



4.



RESTORATIONS.

DALMANIA CORONATA AND OLENUS MITCHINSONI.

G. J. Bayzand del.

Olenus Mitchinsoni, sp. nov. (Pl. XXXV, figs. 5 & 6.)

The specimen under description is about ½ inch long; the head-shield and probably part of the thorax are missing.

The thorax is made up of a number of segments probably greater than ten. Its chief feature is, that from the centre of the axial part of each segment proceeds a spine of considerable dimensions. Those spines nearer the pygidium are in no respect a less prominent feature than those near the head-shield. The pleuræ are grooved, and are sharply bent near their extremities to form posteriorly-projecting spines.

The pygidium is entire, without a well-marked border, and consists of few segments (four to five).

Owing to the absence of the head-shield, and the doubt as to the exact number of segments in the thorax, it is perhaps best to refrain from assigning this form to any one of the subgenera of *Olenus*. I hope before long, however, to be able to describe the head-shield of this interesting species.

This specimen was presented to the Oxford University Museum by the Right Rev. Bishop Mitchinson, Master of Pembroke College, and was found by him in the Shineton Shales of Shineton (Shropshire).

EXPLANATION OF PLATES XXXIV & XXXV.

Plate XXXIV.

Fig. 1. Inner cast of *Dalmania nobilis*. Nat. size.
2. Outer cast of the same. Nat. size.
3. *Dalmania nobilis*. Restored.

Plate XXXV.

Fig. 1. Head-shield of *Dalmania coronata*. ×6.
2. A single thoracic segment of *D. coronata*. ×6.
3. A complete specimen of *D. coronata*. ×6.
4. Outline drawing of *D. coronata*. Restored.
5. *Olenus Mitchinsoni*: specimen laterally compressed. × about 4.
6. Part of a single thoracic segment of the same. × about 6.

Discussion.

The Rev. J. F. Blake and Mr. Lydekker spoke, and Prof. Sollas replied on behalf of the Author.

33. *On an* Anomodont Reptile, *Aristodesmus Rütimeyeri* (Wiedersheim) *from the* Bunter Sandstone *near* Basel. By Prof. H. G. Seeley, F.R.S., V.P.G.S., F.L.S. (Read April 25th, 1900.)

I. Introduction.

Dr. Robert Wiedersheim, of Freiburg-im-Breisgau, has described a remarkably perfect skeleton of a small reptile, which is known as *Labyrinthodon Rütimeyeri*. The remains are a natural mould of the bones, in friable sandstone contained in two slabs, so divided as to display in many cases the under and upper surfaces of the cavities from which the bones have been dissolved away. The fossil was found at Riehen, near Basel, in the Bunter Sandstone; and is preserved in the Museum of the University of Basel. Prof. Wiedersheim made a restoration of the skeleton, which was published in 1878, with figures of both slabs, by the Swiss Palæontological Society.

The animal is said to show no trace of abdominal armour, such as characterizes *Archægosaurus* and most Labyrinthodonts. It does not possess the breast-girdle of median and lateral sculptured bones, found in Labyrinthodonts; and the skin is inferred to have been naked. The external surface of the skull, which would have demonstrated its form and structure, is not available, having been, as Prof. Wiedersheim states, chipped away to expose the internal mould of the head. The bones are said to have been smooth and free from sculpture; and on that account the skull is compared to *Hylonomus* of the Coal Measures.

It was regarded as an Amphibian, in opposition to Von Meyer's view that the Labyrinthodontia are true Reptilia.[1] The type is unique in Europe. The original figures were unsatisfactory, and I applied to the late Prof. Rütimeyer for casts of the slabs; but in his judgment the delicate nature of the specimen did not warrant the taking of impressions, which would show the bones in relief. The photographs which he sent me proved the animal to be an Anomodont reptile, more perfect and interesting than any specimen which was previously known, with the exception of *Pareiasaurus*. Prof. Rütimeyer made application to the Trustees of the Basel Museum to allow me the opportunity of studying the remains in this country. This arrangement was facilitated by the kindness of the late Sir William Flower, who received the fossil on my behalf in the Natural History Museum. Those most experienced in such work were unwilling to take the responsibility of making moulds from the

[1] Prof. Zittel discusses the specimen in a short note in the Neues Jahrb. 1888, vol. ii, p. 257. He doubts the existence of Labyrinthodont structures, and states reasons why the fossil might be a reptile. Further, he quotes a letter in which Prof. Wiedersheim agrees with him in regarding the fossil as a reptile, and indicates some resemblance in it to lizards and to Rhynchocephalia. In 1890 Prof. Zittel ('Handbuch d. Paläontologie' vol. iii, pt. i, p. 597) suggests that it is possibly Protorosaurian, classifying it under Rhynchocephalia.

slabs. Accordingly, in the following description I rely upon impressions of bones, taken by myself from such parts of the skeleton as would manifestly yield prints without the possibility of injury to the matrix.

These impressions suggest modifications of Prof. Wiedersheim's osteological interpretations of the bones. What was regarded as the humerus, I describe as the interclavicle. The scapula of Wiedersheim's fig. 1 is the humerus; the supra-scapula in his fig. 2 is the left coracoid; but in fig. 1 it is the right scapula. The bones interpreted in 1878 as right and left coracoids are the precoracoid and coracoid of the right side of the shoulder-girdle. The bones named clavicles are ribs. A row of teeth drawn upon the palate in the restoration, is doubtfully indicated in the specimen. In place of the four digits to the hand, I find indications of five. These modifications of interpretation reopen the question of the animal's organization. The only alternative supported by evidence of structure is, whether the remains should be referred to a Triassic mammal, or to an Anomodont reptile. Against a mammalian interpretation is, firstly, the presence of a large parietal foramen; and secondly, a composite structure of the lower jaw. There is also the presence of prefrontal, and perhaps postfrontal, bones in the skull, though as the external surface has been chiselled away the evidence on these points is not complete; and at the close of this paper evidence is adduced to show that those bones are found in *Ornithorhynchus*, together with a reptilian structure of the malar arch.

The Anomodont structure may be affirmed, firstly, on a general resemblance of the skull to the skull in *Procolophon*; secondly, there is absolute correspondence of the shoulder-girdle with that region in Anomodont types, and a close approximation to *Procolophon*; thirdly, the great transverse expansion of the proximal and distal ends of the humerus, which, like the shoulder-girdle, is only paralleled in Anomodonts and Monotremes; fourthly, a general correspondence of the vertebræ in plan, and especially in the articulation of the ribs, with *Pareiasaurus* and *Echidna*; fifthly, the Anomodont form of the pelvis, without an obturator-foramen between the ischium and pubis, or a perforation in the acetabulum; sixthly, the close parallelism in form of the femur to *Echidna*; seventhly, the general resemblance of the tibia and fibula to those of *Pareiasaurus*; and, eighthly, the structure of the tarsus, where the proximal row consists of a single bone formed from the anchylosed astragalus and os calcis.

The most distinct approximations to *Procolophon* are the unanchylosed condition of the bones of the shoulder-girdle and pelvis; and the form of the skull, and smooth condition of the skull-bones. In so far as the fossil diverges from *Procolophon* and *Pareiasaurus*, it approximates to *Echidna*, especially in the characters of the limb-bones, such as the humerus, ulna, femur, fibula, and proximal elements of the tarsus.

As the genus is new, the fossil may be known as *Aristodesmus Rütimeyeri* (Wiedersheim).

II. Description of the Fossil.

The Skull.

Prof. Wiedersheim states that the surface of the skull was smooth and without sculpture. The cast from the interior of the skull gives practically no evidence of the extent of the cranial bones, individually. The skull-bones which roofed over the head were unusually thick, especially between the orbits of the eyes, where the frontal bone is quite crocodilian in its thickness, flattened inferior surface, and the way in which the orbits excavate its sides concavely. These lateral curvatures are the chief means of determining the positions of the eyes: they appear to have been placed in the middle length of the upper lateral margin of the head.

In general form the skull is triangular, about intermediate between *Procolophon* and *Pareiasaurus*. Apparently the head was closed behind, more on the pattern of *Rhopalodon*, than of South African genera. There is no descending pedicel for the lower jaw. Prof. Wiedersheim figured indications of ten teeth in the premaxillary and maxillary bones, which are represented as having nearly cylindrical crowns on the right side; but without any indication of separation of incisors from molars, by a functionally developed canine. In this respect, *Aristodesmus* parallels *Procolophon* and *Pareiasaurus*. The snout is flattened, and transversely rounded in front. The nares were manifestly terminal, though they are not preserved.

The internal mould of the skull in *Procolophon* makes a close parallel to this fossil in the flattened, rounded, pre-orbital nasal region, which is traversed by similar longitudinal ridges beneath the nasal bones. The sides of the skull contract in front of the orbits, in a way that is characteristic of *Procolophon* and of many Theriodonts.

On the palate there are obscure appearances, as of broken crowns of short lateral rows of palatal teeth, like those of *Procolophon*.

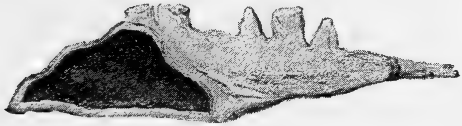
The Mandible and Teeth. (Figs. 1 & 2, p. 623.)

The lower jaw is very short as compared with the length of the skull, resembling in this respect both *Pareiasaurus* and *Procolophon*. The relation in length between the lower jaw and the skull in *Pareiasaurus* is as 11 : 16, in *Procolophon* as 13 : 20, and in this fossil as 12 : 16, showing very similar proportions. In the inferior slab, the under aspect of the jaw is exposed. It has a broad V-shaped form, which rather recalls *Procolophon* than *Pareiasaurus*. The median symphysis is as well-marked on the inner side and base as in either of those genera. The splenial bone appears to form the inner side of the jaw, which is concave from above downward and in length. The inferior suture, which marks its junction with the dentary bone, appears to run along the inferior edge, as in *Procolophon*. As exposed, the inner side of the jaw does not increase

much in depth as it extends from front to back. At the angle of the jaw, which is not much behind its middle length, its depth is greatest. The jaw widens transversely from side to side: seen externally on the left side, it is remarkable for the distinct inferior angular process. There is a prominent longitudinal lateral ridge, towards

Fig. 1.—*Inferior aspect of the mandible of* Aristodesmus Rütimeyeri, *showing the median suture between the rami, the angle, and the composite structure.* (*Nat. size.*)

Fig. 2.—*Teeth in the mandible.* (*Nat. size.*)



the base of the jaw, behind the angle, as though for the attachment of the masseter-muscle. There was no heel extending behind the lower jaw. It may be compared with fig. 5, p. 330 in Phil. Trans. Roy. Soc. vol. clxxxiii (1892) B.

The mandible is not in articulation with the skull, but slightly displaced laterally. The external surface of the dentary bone is tumid, curving forward towards the symphysis. About six teeth are

preserved. The teeth are certainly in distinct sockets: they are placed obliquely in the jaw, so that their anterior margins are inclined towards its inner side. The crowns are sharp-pointed, and moderately prominent, compressed laterally, with sharp lateral ridges, which appear to be serrated. The crowns are inclined inward. A small pulp-cavity descending into the socket is seen in the root of one tooth. In another tooth the smooth enamel appears to show the delicate transverse lines of growth.

The coronoid element appears to be somewhat elevated, rising behind the teeth on the inner side of the jaw.

The Vertebral Column.

Prof. Wiedersheim counted thirty-four to thirty-six vertebræ, grouped as twenty-one or twenty-two pre-sacral, two or three sacral, and ten to twelve caudal. There appear to me to be twenty-two or twenty-three in advance of the pubis, four or five in the ischio-pubic region, and about nine of the caudal vertebræ are behind the pelvis, so that I count a total of thirty-six vertebræ.

The neck, owing to the forward position of the shoulder-girdle, is obscurely defined. There is no evidence of ribs in the earliest vertebræ.

On the right side there are sixteen pre-pelvic ribs preserved, all of which have the characters of dorsal ribs. This would appear to limit the cervical vertebræ to seven.

It is probable that the sacral vertebræ did not exceed three in *Aristodesmus*. Hence the vertebral formula may read as seven cervical, sixteen dorsal, three sacral, and ten caudal.

The centra are so exposed as to show their deeply biconcave articular ends, with the cups penetrating much as in *Anthodon* and *Mesosaurus*, so as to be only slightly separated one from the other in the middle of the centrum by a narrow partition of bony substance. The only centrum in the dorsal region from which the form can be obtained perfect, is on the ventral border as compared with the neural border of the relative length of 2 : 5.

This may suggest that the back was unusually convex; the same effect would result from intervertebral elements on the ventral border. Hence as the vertebræ all lie in the same plane, their visceral articular borders are well separated one from the other. The anterior face of the centrum is larger than the posterior face. The form is subtriangular, with the external margin thickened and rounded. The lower half of the posterior articular face appears to make an angle with its upper part: I can only interpret the angle as due to an intercentrum.

The sides of the centra are concave from front to back, and their surfaces converge inferiorly with a somewhat pinched aspect, so as to form a narrow rounded base to the centrum.

The transverse processes to which the ribs are attached, given off from the sides of the centrum, are strong, and placed high up, though not reaching the anterior articular face. These processes are

concave back and front from within outward, and compressed at the antero-inferior margin into a ridge which descends upon the centrum towards the middle of its articular border. All the characters of the transverse processes of *Pareiasaurus* are intensified in this animal, so far as comparison can be made.

The neural arches of the vertebræ have a quadrate form, and the neural spine is vertical.

The most striking feature of the neural arch is the transverse process, which gives attachment to the rib. These processes extend transversely outward, so as to be horizontal, immediately behind the pre-zygapophyses, and slightly in advance of the middle length of the vertebra. A notch which indents the side of the vertebra, between the posterior zygapophyses and this process, defines its posterior side. Its anterior border, also vertical, is defined by extending beyond the pre-zygapophyses. As exposed, these articular surfaces, which terminate the transverse processes, are nearly vertical truncated facets, slightly concave and converging a little inferiorly. There is no indication of a transverse division between the part of the articulation which is upon the neural arch and that upon the centrum; but as the articulation on the centrum is appreciably narrower, there may be an angle between the two portions of the rib-facet.

The pre-zygapophyses extend forward from the front of the transverse processes like jutting ledges. Seen from above they are sub-quadrate, horizontal, each a little wider than long, and approximate towards each other at the base of the neural spine. The facets are defined by a concave notch between them. The buttresses beneath the facets are margined by lateral ridges. The neural canal is of moderate size.

The neural spine is vertical, triangular, and strong without being massive. The posterior zygapophyses are well defined, compressed, rounded ridges, which continue the posterior angles of the triangular neural spine downward, outward, and backward. The concave posterior surface of the neural spine becomes a wide notch between the posterior zygapophyses. The summit of the neural spine is truncated and rounded.

Compared with *Pareiasaurus bombidens*, the stronger transverse process is more elevated.

There may be some approach in form of neural spine and transverse process to *Protorosaurus*, though the preservation of the specimens of that genus is less satisfactory.[1] Another approximation is seen in *Nothosaurus*, in which the rib has a deep vertical articular facet on the vertebra. The resemblance derives some interest from the structure of the Nothosaurian shoulder-girdle.

The Ribs.

In his restoration Prof. Wiedersheim represents twenty-one pairs of pre-sacral ribs, while there are no ribs to the first vertebra.

[1] This is not supported by the figure given by Franz Etzold, Neues Jahrb. 1898, vol. ii, p. 148.

I am not able to count more than sixteen ribs in sequence on the right side of the dorsal region, and am disposed to think that that number includes the whole of the dorsal series. The earliest are short. There appear to be indications of a few small sternal ribs, between the interclavicle and the coracoids; but the disturbed preservation makes such identification of those ribs very uncertain. Behind the region of the scapula the dorsal ribs attain their maximum length, seen in about half-a-dozen long ribs which follow the first few shorter ones. Then the ribs steadily decrease in length. They are strong without being massive; curved from above downward and outward; compressed from side to side; and somewhat flattened on the rounded dorsal surface. Their extremities terminate abruptly in truncated surfaces. There is no indication of abdominal ribs, such as characterize *Hyperodapedon*, *Mesosaurus*, *Protorosaurus*, and the Plesiosaurs.

The Sacrum.

The transverse width of the sacrum is due to the elongation of straight, horizontal, transverse processes or sacral ribs, which extend outward at right angles to the axis of the vertebral column.

Upon the upper half of the inner side of the left ilium above the acetabulum there is an impressed area which covers the width of the bone. It presumably indicates the articulation of the sacrum, and may comprise four narrow, deep, vertical impressions of greatly expanded ends of sacral ribs, as in *Pareiasaurus*, only longer.

The Caudal Vertebræ.

Behind the sacrum the vertebræ rapidly become very short. There are at least three vertebræ in close contact one with the other indicated as resting upon the left ischium, and those vertebræ are probably caudal though they are in close contact. Behind them, separated by a slight interval, are indications of nine or ten vertebræ which form the remainder of the tail. The bodies of the vertebræ become successively shorter, and the interspaces between them are well-marked. Their shortness is a distinctive character. The neural arch is well developed, and in the first four vertebræ of the series there appear to be short chevron-bones freely articulated. The posterior surface of the centrum forms oblique facets for articulation of the chevron-bones.

The Shoulder-Girdle. (Fig. 3, p. 628.)

The shoulder-girdle presumably includes nine bones, but I have not recognized the clavicles. The remaining seven elements comprise five bones on the ventral surface. First a median T-shaped interclavicle, which does not differ appreciably from the 'pickaxe'-bone in *Ichthyosaurus* and African Anomodonts. Behind each of its long lateral transverse bars is a pair of bones, thin and disc-shaped, which are divided from those of the opposite side by the longitudinal

staff of the interclavicle. These bones are the precoracoid and coracoid. Laterally, the two scapulæ extended upward and backward dorsally over the ribs. These bones form a strong pectoral girdle. The head of the humerus is preserved in close contact with the articular face of the coracoid. The bones of the shoulder-girdle are situate far forward, just behind the animal's head, as in *Pareiasaurus* and *Procolophon*. The antero-posterior extent of the bones corresponds to about four vertebræ. In general character the shoulder-girdle is Anomodont. *Pareiasaurus* and *Rhopalodon* have the constituent bones anchylosed together, while this rather resembles *Procolophon* and *Keirognathus*. The former has a similar interclavicle, but exhibits closer union between the precoracoid and coracoid. The latter appears to have the precoracoid and coracoid similarly free; but its interclavicle is in form unlike the bone in other Anomodonts. The resemblance to *Eryops* deserves attention, though the shoulder-girdle bones are united in that Labyrinthodont.

(*a*) The Interclavicle.

There is a general correspondence of T-shaped form between this bone and the interclavicle in *Procolophon* and *Pareiasaurus*. The chief difference in these types is in the parallelism of the sides of the longitudinal staff of the bone in *Procolophon*, and the posterior divergence of the sides in *Pareiasaurus*, in which however the extremity of the staff of the bone is imperfectly preserved. In this Bunter fossil the interclavicle is intermediate in character between those genera, for there is a very slight posterior widening of the staff, and it is so short as not to extend back beyond the middle of the coracoids.

The indications preserved on the right side give a transverse width to the bar, so that it is actually longer than the staff. In *Procolophon* the staff is much longer than the transverse bar. In *Aristodesmus* the bone is relatively rather small, since the transverse bar, which is inclined a little backward, does not extend laterally outward so far as does the precoracoid. This character may not be of much importance, since in *Keirognathus* the lateral arms of the interclavicle are very short, and the clavicles rest upon the anterior margins of the precoracoid bones. In *Pareiasaurus*, on the other hand, the lateral arms of the interclavicle extend outward beyond the precoracoids, so as to completely separate those bones from the clavicles, which are carried in front of the interclavicle upon the transverse bars. The widening of the staff of the interclavicle, at its hinder extremity, exceeds ·4 inch. In its middle length the width is ·3 inch; and it widens again anteriorly towards the transverse extension of the anterior bar. These lateral arms measure from front to back at their origin about ·3 inch, and ·1 inch each at the outer extremity.

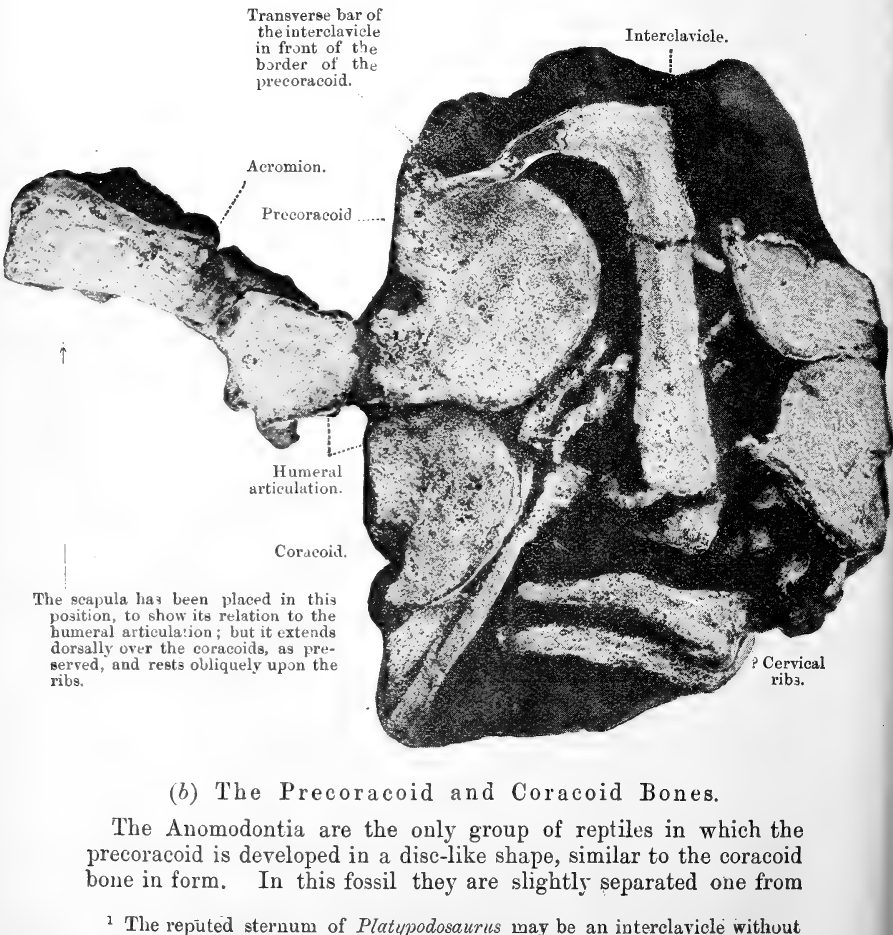
The external surface of the interclavicle is elevated. This makes a flat median longitudinal surface, on each side of which the staff is slightly grooved. The grooving is not distinct at the posterior

extremity of the bone. There is an ossification behind and below the posterior extremity of the staff, which is of small size, imperfectly exposed. It may be the extremity of a small sternum: a sternum is found in Anomodonts.

Its resemblance to the interclavicle of *Saurosternon*, which is an Anomodont, had not escaped the notice of Prof. Wiedersheim. It differs from the interclavicle of *Echidna* in the longer staff, and less expanded extremities of the bone. The staff is not developed in *Eryops*.[1]

The clavicles have not been recognized.

Fig. 3.—*Portion of the shoulder-girdle of* Aristodesmus Rütimeyeri. *(Nat. size.)*



(b) The Precoracoid and Coracoid Bones.

The Anomodontia are the only group of reptiles in which the precoracoid is developed in a disc-like shape, similar to the coracoid bone in form. In this fossil they are slightly separated one from

[1] The reputed sternum of *Platypodosaurus* may be an interclavicle without a staff.

the other. They may have diverged a little posteriorly, like the bones in *Echidna*.

The external surface of the right precoracoid is a little longer than wide. Its inner border is convex from before backward, so as not to correspond with the contour of the interclavicle. The external border has a lateral notch in the middle: this appears to divide the thickened posterior part, which adjoined the scapula, from the anterior part. A similar notch is seen in the precoracoid of *Procolophon*, and apparently in *Keirognathus*; but the conditions are dissimilar in *Pareiasaurus*, *Rhopalodon*, etc., in which a foramen is developed at the junction of the precoracoid and coracoid, and not between the precoracoid and scapula as in the other known Anomodont genera. The external surface of the precoracoid is flat, with the internal and posterior margins slightly raised. The internal articular edge of the precoracoid is vertically truncated, in the manner seen in the expanded coracoid bones of the shoulder-girdle in Plesiosaurs and Ichthyosaurs, forming a narrow edge which is rough and cartilaginous.

The coracoid is nearly as long as the precoracoid. Its transverse width as preserved is less. It is a somewhat lunate plate, convex on its interior margin, with the posterior margins retreating outward in a convex curve. The bone appears to be flattened on its visceral surface. The external border is divided into two parts: the anterior half forms the articulation for the humerus. But behind this thickened border the bone appears to be concavely notched on the side.

It is not certain that these bones came into median contact. They may have united with a cartilaginous sternum, but there is no evidence of such a structure.

(*c*) The Scapula.

The right scapula extended dorsally over the ribs, above the coracoid and precoracoid. The bone is moderately long, curved in length, so as to be adapted to the ribs, inclined a little backward, compressed from above downward. Its thickness augments from the middle length to the humeral articulation. The free extremity is transversely truncated, and the middle length of the blade narrower.

At the proximal end the width is divided into two articular parts: an anterior, sutural, precoracoid portion, and a posterior, glenoid, humeral portion. The posterior margin is the more concave, thicker, and more regularly rounded. The anterior lateral margin is nearly straight, and compressed to a sharp edge. The external surface of the bone is flattened, as in *Pareiasaurus* and *Rhopalodon*, and gives no indication of a twist such as elevates the anterior margin of the bone in African Theriodonts, and apparently in some Dicynodonts. There is an imperfectly preserved anterior mesoscapular thickening or slight acromion-process on the middle of the anterior border of the bone. The bone is not unlike the scapula of *Pareiasaurus* in proportion; the acromion appears to have been similarly placed.

Affinities of the Shoulder-Girdle.

The shoulder-girdle has its first affinities with the Anomodontia, in the second place with the Monotremata, and in the third place with *Eryops*. The first affinity with the Anomodontia, and the second with the Monotremata, are of the same order. In wanting the anchylosis of the precoracoid to the coracoid and scapula, *Aristodesmus* differs from the Russian Deuterosauria, the Pareiasauria, and apparently the Theriodontia.

The loose relation of the precoracoid to the coracoid is not perhaps more marked in *Echidna* than in *Keirognathus*. In *Procolophon*, although the union appears to be sutural, it is a straight suture.

Affinity with *Procolophon* is most evident in the forward extension of the precoracoid, so that it has a lateral surface in advance of the scapula. This character is a distinction from all other Anomodonts, and supports the classification of *Procolophon* as a primary division of the group, well distinguished from Pareiasauria.

The Fore-Limb. (Fig. 4, p. 631.)

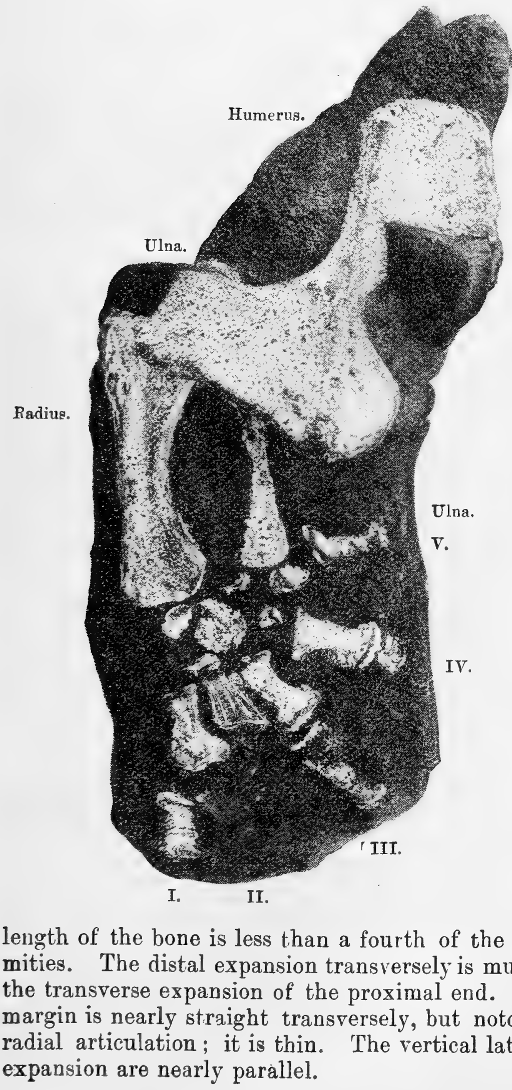
The bones of the fore-limb are only evidenced on the right side of the body, though fortunately there are superior and inferior impressions of the humerus, ulna and radius, carpus, metacarpus, and digits. In form, proportion, and many details of structure, the limb somewhat resembles *Echidna*. These Monotreme characters extend to the form of the humerus, the proportions of ulna and radius, and the general aspect of the digits; though the phalanges are relatively longer, and the claw-phalanges relatively rather smaller. Prof. Wiedersheim has drawn four digits in his restoration of the fore-limb, and four only are preserved on each slab. There appears to be evidence of five digits, by superimposing the upper and lower surfaces. Five is also the number in the hind-limb. One remarkable feature of the fore-limb is the way in which the fifth digit is directed outward at right angles to the ulna; and the outermost digit is directed forward below the radius, so that the five digits radiate towards the outer side of the foot.

(*a*) The Humerus.

The ventral surface of the humerus shows the transverse expansion, and concavity from side to side, of the proximal fan-shaped half of the bone, which is in articular relation with the coracoid and is relatively wider than in *Echidna*. This transverse extension and the absence of an hemispherical head are shared with Anomodonts. The proximal articular surface is narrow and long, with downward reflexion of the radial part of the bone. Its articular surface is markedly convex along its length: the convexity consisting of two portions, which, though not sharply defined, are inclined one to the other at rather more than a right angle.

The articular part of the proximal end of the humerus is narrower than the radial crest. The bone is flattened superiorly, with a tendency to be concave from above downward; and it makes an angle of about 45° with the radial crest, which is of similar size and form. The longitudinal lateral margin on the ulnar side of the bone is much more concavely excavated proximally than the radial side, behind the talon-like process.

Fig. 4.—*Right fore-limb of* Aristodesmus Rütimeyeri. *(Nat. size.)*



The entire humerus is compressed, so that its lateral margins are thin. The compression and the twist in the bone are like those known in *Protorosaurus*, *Dicynodon*, and *Rhopalodon*, though it is more like the humerus of *Echidna* in the expansion of its proximal and distal ends. The twist of the bone makes the curved lateral contour on the radial side appear to be deeply concave; the concavity on the ulnar side of the bone is deeply excavated.

The transverse width of the middle of the shaft below the middle length of the bone is less than a fourth of the width of its extremities. The distal expansion transversely is much more rapid than the transverse expansion of the proximal end. The inferior distal margin is nearly straight transversely, but notched external to the radial articulation; it is thin. The vertical lateral borders of this expansion are nearly parallel.

The distal end of the bone has a sort of hammer-headed appearance. The superior surface is smooth, inflated proximally on the ulnar side by a broad convex ridge, which prolongs the convexity of the shaft obliquely across the expansion of the distal end of the bone towards the ulnar side, exactly as in *Dicynodon*. The ridge makes the middle part of the distal end a shallow concavity, with the middle of the distal margin notched; but the concavity is less marked than in Monotremes. There is a small flattened triangular articular surface for the ulna; and there appears to be a second long and narrow articular surface for the radius.

The essential differences from *Echidna* are in the absence of the strong lateral curvature, which causes the twisted proximal end of the bone in Monotremes to curve laterally towards the distal end. This divergence from the Monotreme type is emphasized by three other differences. Firstly, absence of a vascular perforation through the distal end of the bone in the fossil; secondly, limitation of the two facets for the distal articulation to the inferior surface of the bone; and thirdly, the lateral border is a simple open curve from the proximal end to the distal expansion, unbroken by processes.

Comparisons with the humerus in burrowing animals, such as the mole, suggest that the transverse expansions of the extremities of the bone, the curve of the proximal articulation downward, and the lateral position of the distal articulation, may all be adaptive modifications; and that the difference between the Insectivore and the Monotreme in structure of the humerus is not greater than, even if so important as, the difference between the Monotreme and this fossil.

The value of the resemblances to mammalia as marks of affinity can only be determined by the extent to which the characters are shared by animals which there is no ground for regarding as mammalian. Thus the transverse expansion of the proximal and distal ends of the bones, the constriction of the middle waist of the humerus in the fossil, the downward direction of the radial crest, the unbroken contour of the ulnar border, the absence of a foramen opening on to the superior surface on the ulnar side, as well as the long narrow articular surface at the proximal end, are characters found in the humerus of *Protorosaurus*, though they are not developed in the same degree; and therefore in all those points in which difference from the Monotreme is most pronounced, there is a reptilian approximation.

Most of the characters seen in the Permian reptile *Protorosaurus* are also found in the different animal types which have been referred to the Anomodontia. Sir Richard Owen figured four in the humerus of *Dicynodon*—the transverse expansion of the proximal and distal ends, the constriction of the waist of the bone, the smooth contour of the ulnar border, and the downward reflexion of the radial crest at the proximal end. In details there are striking differences, for all these points are intensified in *Aristodesmus*. On the other hand, in *Dicynodon* the articulation of the bone makes a

rounded distal surface to the humerus as in *Rhopalodon* and allied types, while in this fossil the resemblance in the mode of articulation of the radius is closer with Monotremes. Several types of humerus are included under the Anomodontia. In *Pareiasaurus* the distal expansion of the bone may be so far lost, that it extends only a short distance on each side of the trochlear articular surface. The expansion of the proximal end, the constriction of the shaft, and the reflexion of the radial crest are closely paralleled in *Procolophon*. The variability of the humerus in Theriodonts such as *Herpetocheirus* and *Theromus* leads to the conclusion that many of the resemblances of *Aristodesmus* to *Echidna* are adaptive modifications; that the affinity of *Aristodesmus* to the Anomodonts is much closer than to *Echidna*; and that *Aristodesmus* approaches more closely to *Echidna* than any Anomodont hitherto known.

(*b*) The Ulna and Radius.

The ulna and radius are unequal strong bones exposed side by side. Their proximal ends are partly hidden beneath the distal end of the humerus, and they are not easily determined, because there is some appearance in one impression of the slender bone extending beyond the transverse process of the distal end of the humerus, so that the ulna is anterior to the radius, as in *Ornithorhynchus*.

The radius is a flat strong bone, its transverse width greatly exceeding that of the ulna. The proximal end is wide, and transversely truncated. The distal end is a little narrower, and exceptionally convex from within outward. There is some appearance of a contact-surface upon the radial border of the distal end, but no corresponding surface is seen upon the ulna. The inner side of the radius is markedly concave. The external borders of these bones are relatively almost straight. A shallow vertical channel begins in its lower third, and increases in depth proximally. This makes a prominent ridge at the proximal external border, which shows ligamentous roughnesses; and on the inner side a ridge is strongly developed, thickening the bone, which widens the radius so as to come into contact with the ulna at its proximal end.

The stoutness of the radius is a divergence from some African Anomodonts, in which the condition of the bone is at present imperfectly known. There is some evidence that the proximal end of the ulna extended appreciably beyond the radius in the manner of *Herpetocheirus*.

The ulna is more expanded and massive at the distal than at the proximal end; it has the shaft somewhat flattened behind, and narrowed in front by side-to-side compression. The distal articulation is a truncated transversely-ovate flat surface wider than deep, which has a sharp margin, and is inclined somewhat obliquely. There is no single carpal bone exposed which would fit the distal extremity of the ulna. The sides of the ulna are concave from above downward, especially the inner border, its external side being

straighter. On the anterior surface, the proximal is slightly wider than the distal end. A portion of the shaft is wanting.

The radius gave attachment to the larger part of the carpus.

The large size of the radius as compared with the ulna, and the expansion of the ulna at the distal end, are the distinctive features of this segment of the limb, and derive their importance from the resemblances which other parts of the skeleton show of the same type. Both Monotremes have these two bones unlike the fossil in details. The olecranon-process is developed in the following Anomodont-types:—*Pareiasaurus*, *Procolophon*, *Keirognathus*, *Theriodesmus*, and apparently in *Herpetocheirus*; while there is no indication of an olecranon-process in *Eurycarpus Oweni*. In the latter genus there is evidence of pronation in the crossing of the ulna over the radius, and in that genus also the proximal ends of ulna and radius are articulated, side by side, to the distal end of the humerus.

(*c*) The Carpus.

The carpal bones number 6 or 7. They are separated one from the other, and are mostly of small size; it is difficult, therefore, without the aid of cartilages, to suppose that the proximal ends of the metacarpal bones could have articulated with the carpal elements preserved. In the superior aspect there are not more than four bones that can be counted as proximal, two below the radius and two below the ulna. Two are manifestly distal, and between these and the proximal bones is a large ossification.

(*d*) The Metacarpus.

The inferior aspect of the slab shows four metacarpal bones, and the upper surface shows five. The hand is bent backward, and the digits radiate outward. The first is directed forward and the fifth is directed outward.

The metacarpal bones are longer on the superior aspect than on the under side, and the bones are individually broader. The proximal ends are flat with a prominent margin. The sides are concave, the concavity being emphasized by the expansion of the extremities. The distal end is thickened and rounded.

(*e*) The Digits of the Hand.

The phalanges are much shorter than the metacarpal bones. They show the short broad form with expanded ends, and a distal trochlear extremity. In the first digit there appear to be two phalanges, without indication of the claw-phalange. In the second digit are three phalanges and the claw. The third includes three bones. The fourth comprises three phalanges; but whether the third is the claw-phalange is uncertain. The fifth only shows two phalanges preserved, without any indication of the claw. The claw-phalanges are exposed on their inferior surfaces: they have an inferior callosity below the articulation; are long, pointed, curved, and compressed, so that they carried sharp claws.

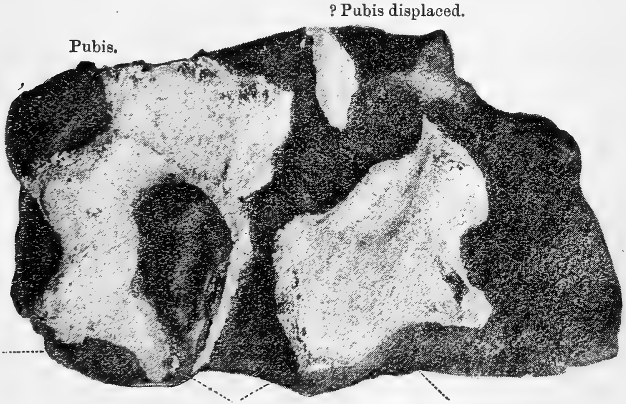
The Pelvis.

The pelvic basin is formed by the pubis and ischium, of which only the inner or visceral surface is seen. The bones of the left side are in sutural union throughout their length, but the form of the anterior margin of the pubis is not evident, nor is the whole shown of the pubic part of the acetabular border. The absence of an obturator-foramen between the pubis and ischium is a character shared with *Pareiasaurus* and *Procolophon*; a median sutural union occurs in the Cetiosauria, but the forms of the bones are dissimilar.

(*a*) The Ilium. (Fig. 6, p. 638.)

The right ilium was almost vertical, being very slightly inclined forward. The bone is moderately deep, from the superior slightly convex margin of the iliac crest to the middle of the inferior angle of the acetabulum, which was imperforate, in the way that has been described in various South African Anomodonts. The bone is convex from above downward. Its anterior and posterior margins are reflected outward, so that the blade of the bone, which is ·9 inch wide, is concave from side to side, and convex from above downward. The blade is very slightly expanded from front to back.

Fig. 5.—*Visceral surface of pubis and ischium in* Aristodesmus Rütimeyeri. *(Nat. size.)*



(*b*) The Ischium. (Fig. 5.)

The right and left ischia were inclined together, and united by a median sutural surface, so as to form with the pubic bones a broad basin of moderate depth. The ischium has a subquadrate aspect, owing to the straight transverse suture, which separates it

from the pubis, and the straight longitudinal suture, equally long, which divides it from the bone of the opposite side. Both the posterior and external borders of the ischium are concave; and the antero-posterior measurements internally and externally are similar, so that the approximation in form is rather towards *Pareiasaurus* than *Procolophon*. An external lateral area, concave from above downward, is defined by a thickened ridge which strengthens the bone and extends backward. It is shorter from front to back than in *Dicynodon leoniceps*, in which all the pelvic bones are anchylosed together. The ischium moreover approximates in type to *Procolophon*, but in that genus also the anterior margin of the bone terminates superiorly in a point. The pelvic acetabulum excavates the bone concavely in front, being defined by posterior and anterior ridges, more on the type of *Phocosaurus* than of *Dicynodon*, though without the superior wedge on the ilium to support the head of the femur, which *Phocosaurus* possesses in common with some Theriodonts. The acetabular surface of the ilium has the bone greatly thickened on its internal border, and the thickening recedes from the pubic articulation, so as to define a thin concave area in front of the mass of the bone. If this thin portion were absorbed, a large transverse obturator-foramen would appear, which would bring the pelvis into easy comparison with the pelvic bones of Plesiosauria. This transverse union between the ischium and pubis is the character which seems of greatest value in illustrating the affinity of the pelvis with that in *Procolophon*. The most distinctive feature, however, is in the prominence of the thin concave posterior border of the bone in this fossil, which lies between the longitudinal median suture and the thickened posterior angle of the bone.

(*c*) The Pubis. (Fig. 5, p. 635.)

The pubis is not quite so wide as the ischium, and is about half as long from front to back. The bone is remarkable for its shortness from front to back, in which character it agrees with other Anomodonts, and especially with *Procolophon*, though the transverse width of the bone is relatively much greater than in *Procolophon*. There appears to be a thickening of the anterior margin of the bone, but whether that is a normal character is not demonstrated by the evidence available. The relative narrowness of the pubis, as compared with the ischium, has the effect of throwing the blade of the ilium forward.

The Hind-Limb. (Fig. 6, p. 638.)

There is little difference in length between the humerus and the femur, which is equal to the length of four or four and a half vertebræ. The fore-leg is relatively and actually a little shorter than the fore-arm.

The Monotreme characters of the bones are rather more conspicuously developed in the leg than in the arm; for though the

resemblance to *Echidna* is most striking in the femur and humerus, it may be considered that the prolongation of the fibula proximally so as to extend beyond the tibia is an approximation, as far as it goes, to Monotreme character. The bones of the fore-leg are capable of rotation, such as usually occurs in the fore-arm, the fibula crossing the tibia obliquely. This probably indicates use of the hind-limbs in burrowing.

(*a*) The Femur.

The femur is slender, compared with the massive femur of *Pareiasaurus*, or even with the femur of *Echidna*. There is some appearance of a twist in the bone, which is due to the slight transverse expansion of the distal end. The affinities of the bone are closer with *Echidna* than any known Anomodont, but the Anomodont femur is less fully known than the humerus. The proximal end of the bone has a smaller articular head than is seen in *Echidna*, and although prominent so as to extend above the adjacent surfaces, is less prominent than in *Echidna*, and may not reach quite to the inner margin of the bone. The trochanter minor is prominent on the inner margin, near the proximal end, and the ridge which it forms is prolonged down the shaft. It is unlike the corresponding ossification in *Ornithorhynchus*, *Rhopalodon*, *Pareiasaurus*, *Tribolodon*, or *Cynognathus*. The trochanter major is a thin external film which widens the shaft. In *Echidna* it extends more than halfway down the length of the femur; but while the trochanter is of exactly the same type in this fossil, terminating in a straight external edge which is thin, it is less expanded transversely, and less than half as long as the bone. The vertical direction of the head of the bone upward in the fossil, rather favours comparison with the Monotreme. There is no close correspondence with the Cynodont type of femur, characterized by the singular transverse expansion of the proximal end of the bone, and forward reflexion of the short trochanter major, seen in *Cynognathus* and in *Tribolodon*.

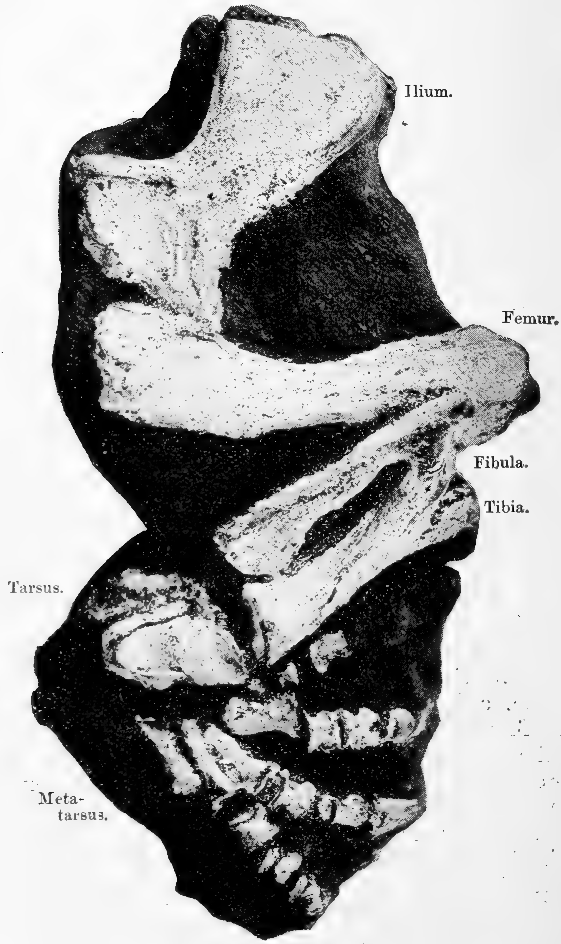
A similar restriction of the trochanter major to the proximal end of the bone, and a longitudinal development of the trochanter minor in *Microgomphodon*, distinguish that genus equally from this fossil and from *Echidna*. *Pareiasaurus* is the Anomodont that approaches nearest to this femur, which in its proximal end is intermediate between *Echidna* and *Pareiasaurus*, and appreciably nearer to the latter than to the former. It makes no approach in the proximal end to the femur in *Procolophon*, which is massively triangular, with a deep excavation behind the articular head on the under side of the bone, between the small marginal major and minor trochanters, being more intermediate between *Pareiasaurus* and *Ornithorhynchus*.

The middle of the shaft, on its superior aspect, is well rounded from side to side.

The femur appears to widen transversely at the distal end, while its depth is augmented by the articulation with the fibula and

tibia. The exposed condylar surfaces of the distal end are rounded from above downward. The lower half of the shaft is longitudinally channelled in front by a deep groove, which stops short abruptly above the distal extremity, and appears to penetrate into the bone

Fig. 6.—*Right hind-limb of* Aristodesmus Rütimeyeri. *(Nat. size.)*



between the condyles in a foramen, in the way seen in the femur of *Propappus* and *Pareiasaurus*. There is some approach to this channelling of the distal articulation of the femur in *Iguanodon* and some Ornithischian reptiles; but I have not observed it in any

of the Saurischia, or indeed in any other Anomodonts. The distal articulation appears to truncate the distal end of the bone somewhat obliquely, in the manner seen in *Pareiasaurus*. It makes no approach to the trochlear condition of the femur in *Tribolodon* and other Theriodonts. The internal condyle of the femur is more developed than the outer condyle.

(*b*) The Tibia and Fibula.

The fibula is produced proximally into a process like the olecranon-process of an ulna: a character which may be present, but is not clear in the ulna itself. The tibia is a stout bone, while the fibula is comparatively slender. In both these Monotreme characters, as well as in form and curvature, there is some approximation to the tibia and fibula in *Cryptobranchus*, the giant salamander of Japan.

The proximal end of the tibia, which is sub-reniform, is divided into two surfaces, corresponding to the two condyles of the femur by a deep vertical groove. The fibula does not lie in the groove of the tibia, but articulates by a definite surface with the hinder margin of the proximal end of the bone. The sides of the tibia are concave, and upon this middle portion of the shaft a sharp ridge crosses obliquely from its external or fibular side to its internal border. The distal end expands transversely, is somewhat compressed, but moderately convex, with the fibular margin gently concave, and the internal border gently convex. The fibula slightly overlaps the tibia in front, and articulates with it by a small surface.

The fibula contracts in the middle, and expands at the proximal end somewhat abruptly. Its proximal articular surface is oblique and concavely excavated, forming a concavity for the femoral condyle, though the fibula does not appear to be prolonged proximally appreciably beyond its articular surface. The internal border of the bone is concave; the external border is straight. The bone maintains a nearly uniform thickness from end to end, becoming somewhat flattened externally; it is margined laterally by a slight ridge in its lower half, which helps to make the distal end of the bone very slightly concave.

In *Pareiasaurus* the proximal end of the fibula appears to have been greatly expanded, and terminated backward in a vertically compressed plate. It is only known from the left fibula of *Pareiasaurus Baini*, found resting horizontally on the spines of the vertebræ in advance of the sacrum.[1] That form of proximal end is essentially a modification of the Monotreme type in its expansion, but it shows a certain resemblance to *Aristodesmus*, in which the bone is produced a little forward as in *Pareiasaurus* and in *Echidna*. Both tibia and fibula are intermediate between those of *Pareiasaurus* and those of *Echidna*.

[1] See Phil. Trans. Roy. Soc. vol. clxxxiii (1892) B, p. 314, fig. 2, reproduced from my sketch made at Bad before the specimen was removed from the rock.

(c) The Tarsus.

The tarsus is characterized by a great compressed triangular tarsal bone, which consists of two elements blended together. It is compressed from back to front; and I regard the larger part, which articulates with the tibia, as the astragalus. It is possible that both tibia and fibula articulate with the same proximal surface, so that the os calcis may project outward as a thick compressed ossification standing beyond the tibia and fibula. There is a proximal surface transversely truncated, the inner half of which, formed by the astragalus, may alone have given attachment to the fibula.

There is no trace of any bone of the distal row of the tarsus; and presumably the distal elements of the tarsus were cartilaginous.

The great transverse width of the proximal bone is sufficient to have given attachment to about four digits, but the fifth may have been directed internally, though there is no evidence of this position.

(d) The Metatarsus and Digits.

The metatarsals increase in length from the first to the fourth and fifth, but they become successively narrower; the first and second are both broader, stouter bones than the fourth and fifth, and the third is intermediate. They are flattened above, have concave sides, and are somewhat concave on the under side. Their proximal articular surfaces are truncated, with elevated borders; and the distal ends show a moderate rounding, as of a pulley-shaped articulation.

The first digit is strong and short, and consists of a single phalange with the sides deeply notched, followed by a claw-phalange in which a strong triangular callosity is developed below the articulation.

The second digit is much longer, and contains three phalanges; the difference in length being due mainly to the intercalation of an additional phalange. The third digit also includes three phalanges; the bones are not quite so wide as in the second digit. Their aggregate length is the same.

In the fourth digit, which is only seen in the superior aspect, there are four phalanges, which are individually rather smaller than in the third digit, and have similarly short proportions, terminating in a sharp claw-phalange, which is convex on the upper surface.

Of the fifth digit no phalange is preserved. The form of the long metatarsal is consistent with the phalanges having been as well developed as in the other digits. In general form this hind-foot closely resembles the fore-foot of the South African *Eurycarpus*. In the character of the phalanges there is some resemblance to *Echidna*, but the metatarsal bones are different in being stouter than in the Monotreme.

The Armour.

The dorsal surface of the animal appears to have carried two or three longitudinal rows of irregular small scutes, which were isolated one from the other. The rows were widely separated. On the cast, between the impressions of the ribs, are a series of holes, one between each pair of ribs as a rule. Their forms are irregular, identified with uncertainty; they may indicate prominent dermal scutes.

III. Conclusion.

The skeleton now described appears to leave no doubt as to its systematic position. The skull and shoulder-girdle demonstrate a preponderance of Anomodont characters. The Anomodontia in the present state of knowledge are better defined by the structures of those regions than in other parts of the skeleton. But while the shoulder-girdle is distinctly Anomodont, the free condition of its constituent bones makes a partial resemblance to the Monotremata. The pelvis also is Anomodont, so far as can be judged from its state of preservation.

On the other hand, the limbs in *Aristodesmus* make a more decided approximation to those of Monotreme mammals than has hitherto been seen in any fossil, although they also show affinity with the Anomodontia. Judged by the limbs alone, the evidence already available from this genus and African Anomodonts almost obliterates the interval between Monotreme and reptile; just as the evidence drawn from comparisons of the skull alone, tends to keep the two groups distinct.

There is no proof at present that the skull may make a complete transition between the two groups. Chelonian reptiles have shown that the reptilian prefrontal bone may in most genera be combined with the nasal bone, and yet remain distinct in a few types like the fossil *Rhinochelys* and the existing *Podocnemys*. There is no evidence that the union between the frontal and postfrontal bones, or between the dentary bone and other elements of the mandible, is obliterated in reptiles. So long as the lower jaw is composite, and prefrontal and postfrontal bones exist, the animal may be technically a reptile; although the blending of the prefrontal and nasal bones in Chelonians shows the first step in a change by which the reptilian skull might lose its most distinctive characters. The Chelonian modification rather tends towards the possibility of reduction of the reptilian to the mammalian type of skull, but lends no support to a supposition that a mammal might preserve pre- and post-frontal bones, a parietal foramen, or a composite lower jaw. The obliteration of distinct ossifications varies in time of disappearance.

Until the embryology of *Echidna* is known, it would be premature to affirm that the Anomodontia and Monotreme mammalia are not members of a natural alliance, which might be termed Theropsida. From the point of view of the osteologist, it may be a reasonable inference that the interval between the Monotreme

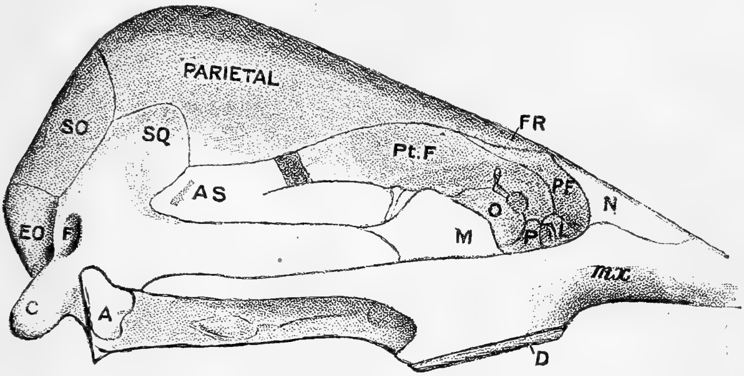
mammal and Anomodont reptile is no more than an ordinal separation. The gap between these two orders is certainly smaller than the gap between *Iguanodon* and other Ornithischian reptiles, and birds. It is not, however, an approximation of the Anomodont type to the mammalian type as commonly conceived which *Aristodesmus* exhibits, but an approximation to the points which are distinctly Monotrematous, and by which the Monotremata differ from all other mammalia, such as the structure of the shoulder-girdle, the general form of the humerus, the stoutness of the ulna, the proximal development of the fibula, and the character of the proximal row of the tarsus. These structures separate Monotremes from other mammals, and link them with Anomodonts. Therefore, having regard only to the oviparous reproduction of the Monotreme, and other reptilian conditions in the structure of its soft parts, there is a sense in which all these characters must be regarded either as reptilian, in view of their occurrence in the Anomodontia, or as Theropsidan in forming a basis for alliance between the Anomodontia and the Monotremata. There does not appear to be any closer approximation to the higher mammals in the Monotremes than is shown in *Aristodesmus* and other described Anomodontia, except in the obliteration of sutures in the skull, the distinctive form of the atlas, and the presence of marsupial bones, which have not yet been recognized in Anomodontia.

The affirmed absence of prefrontal and postfrontal bones in *Ornithorhynchus* deserves better demonstration than has been given. The frontal bones converge forward; their anterior termination is flanked laterally by the nasal bones; but between the nasal and the frontal there is a bone in the front of the orbit, which is above the lachrymal foramen. It corresponds to the prefrontal bone. There is a large separate postfrontal ossification at the back of the orbit, external to the junction of the frontal and parietal. These two bones, which are partly separated from the frontal by a process of the parietal bone, quite exclude the frontal bone from the orbital margin. The presence of prefrontal and postfrontal bones in the orbit in Monotremata goes towards showing that their resemblances to the higher mammalia are associated with reptilian divergences, which establish a closer relation between *Ornithorhynchus* and Anomodontia, and other reptiles, than was obvious. (See fig. 7, p. 643.)

In the skull of *Ornithorhynchus* there is a foramen above the articular surface for the lower jaw, which extends longitudinally from front to back, and is narrower in some skulls than in others. This may be termed the supra-articular foramen. It is stated by Owen to be present in the skulls of some recent reptiles. A foramen is seen in the same position in *Ichthyosaurus*, which lies between the quadrate bone on the inner side and the quadrato-jugal and supratemporal, which extend to the squamosal so as to define its external side. This condition is approximated to in Ornithosauria. There is a foramen above the articulation which is external to the quadrate bone in many Anomodonts,[1] though it is

[1] Phil. Trans. Roy. Soc. vol. clxxx (1889) B, pl. x, fig. 4.

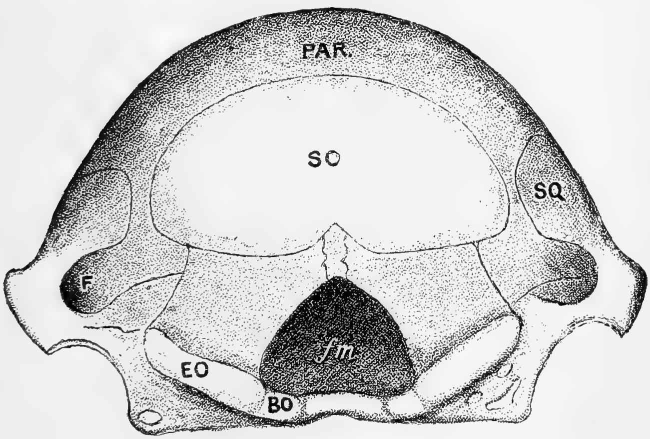
Fig. 7.—*Right side of the skull of* Ornithorhynchus, *showing separate postfrontal and prefrontal bones and the malar bone.* (×2.)



SO = Supra-occipital.
EO = Ex-occipital.
C = Occipital condyle.
SQ = Squamosal.
F = Supra-articular foramen.
A = Articulation for the lower jaw.
AS = Alisphenoid.
Pt.F = Postfrontal.

O = Orbitosphenoid.
P = Palatine.
L = Lachrymal.
PF = Prefrontal.
FR = Frontal.
N = Nasal.
mx = Maxillary.
D = Dental horny plate.
M = Malar bone.

Fig. 8.—*Occipital aspect of the skull of* Ornithorhynchus. (×2.)



fm = Foramen magnum.
BO = Basi-occipital.
EO = Ex-occipital condyle.
F = Supra-articular foramen.

SQ = Squamosal bone.
SO = Supra-occipital.
PAR = Parietal.

[The transverse imperfect divisions in the supra-articular foramina are of uncertain significance.]

very small in *Pareiasaurus*. It appears to be homologous with the Ichthyosaurian foramen. And when the vacuities in the back of the skull are closed as in some Dicynodonts, the quadrate foramen is comparable in position to this foramen in *Ornithorhynchus*; and to the similarly-placed foramen in *Hatteria*, which opens into the postorbital vacuity, and is defined externally by the quadratojugal bone. It is not proved whether the divisions which appear to separate this external film in *Ornithorhynchus* into separate bones may not be tension-fractures due to maceration. But since they are in the place of the quadratojugal bone, there is a possibility that the quadratojugal loses its individuality in the squamosal, which may require examination. If that inference is suggested from the persistence of the foramen, then it would seem worth examination whether the articular area for the mandible represents the quadrate bone, which would also become lost as a portion of the squamosal bone. Owen considered that the presence of a distinct tympanic bone (with which he identified the quadrate bone in the usual position in *Ornithorhynchus*) 'nullifies the supposition that the upper root of the zygoma can be the analogue of the os quadratum in the Ovipara.'[1] (See fig. 8, p. 643.)

The teeth of *Aristodesmus* are not only distinct from those of *Ornithorhynchus*, but appear to be different from those in Anomodonts, resembling a type like *Rhopalodon* in the individual form of the molars, and a type like *Procolophon* in the absence of distinction between teeth in different parts of the series. This resemblance has led to a detailed examination of the evidences of structure in *Procolophon*, which justify me in regarding that type as making (on the whole) a nearer approximation to *Aristodesmus* than any other, notwithstanding considerable differences in the form of the ilium and the proximal end of the femur. It has also shown that the original proposal to place the Procolophonia as a primary constituent group of the Anomodontia, can be better sustained than the subsequent proposal to make it a subordinate group of the Pareiasauria. The back of the skull is devoid of lateral perforations. *Aristodesmus* resembles *Procolophon* in plan of skull, so far as the parts can be compared; and in plan of shoulder-girdle in having the precoracoid extended in front of the scapula, by which they differ from all other Anomodonts.

The pubis and ischium appear to be of the same type in both; though in the limb-bones there are many differences in detail in structures that can be compared.

I propose to place the fossil in association with *Procolophon* as a separate family in the tribe Procolophonia.

The presence of *Aristodesmus* in the Bunter Sandstone is an additional organic link between the Trias and the Permian strata in which other remains of Anomodont reptiles have been found in Scotland, Russia, and France.

I am indebted to Prof. Charles Stewart, F.R.S., for enabling me to

[1] Since this was written Dr. J. F. van Bemmelen has described these structures in the Monotremata; see Koninklijke Akademie van Wetenschappen te Amsterdam, 1899, Zoology, p. 81.

establish the reptilian characters of the skull of *Ornithorhynchus* by examining the skull of a young male in the Physiological Series of the Royal College of Surgeons, No. 323 c [1] in November 1895. I desire also to reiterate my thanks to the Trustees of the Basel University Museum.

DISCUSSION.

Mr. C. W. ANDREWS inquired whether he rightly understood the Author to state that he considered that affinity exists between the pterodactyl *Ornithocheirus*, the mammal *Echidna*, and the proposed new Anomodont genus. He also asked the precise difference between the term 'Theropsida' proposed by the Author, and the terms 'Sauromammalia' of Baur and 'Hypotheria' of Huxley.

Mr. E. T. NEWTON also spoke.

The AUTHOR, in reply, said that the late Prof. Cope had given evidence of the close relationship of the Labyrinthodontia with the fossil Reptilia in the fact that some Permian fossils originally referred to the former group had subsequently been recognized as Anomodonts; and it had been shown that in some Labyrinthodont genera like *Eryops*, there was little if any difference to separate the shoulder-girdle from the Anomodont type. He was unable to recognize any differences of more than ordinal value between Ichthyosauria and typical Labyrinthodontia in the structure of the palate of the skull, both having a long median parasphenoid with similarly formed pterygoid bones, defining the palatal vacuities. He thought that the presence of supratemporal bones behind the orbits in Labyrinthodonts and Ichthyosaurs is as striking a coincidence of structure in the lateral condition of the skull. The vertebræ of *Eosaurus* and other genera, and the ribs, show that in vertebral characters the resemblances between some Labyrinthodonts and *Ichthyosaurus* are as close as are the resemblances between any orders of existing reptiles. He believed that the structure of Theriodonts and other Anomodonts now made the reptilian nature of Labyrinthodonts more intelligible.

He preferred the term 'Theropsida' to 'Sauromammalia' or 'Hypotheria,' because those were hypothetical terms not based upon structures known when they were suggested. The discovery of the reptilian character of the malar arch, and of the presence of prefrontal and postfrontal bones in the skull of *Ornithorhynchus* in 1895, had given a new importance to the resemblances between the bones of oviparous Monotremata and the Anomodont reptilia, and these facts were expressed for the first time in the name 'Theropsida.'

With regard to the diagram shown on the screen, in which the femur of the proposed new Anomodont was placed between the corresponding bones of *Echidna* and *Ornithocheirus*, the diagram was meant to suggest a relationship between Ornithosaurs and Monotremes, both of which have prepubic bones. He first indicated resemblances between Anomodonts and some Ornithosaurs in a memoir upon *Protorosaurus*.

[1] Sir Richard Owen figured a still younger skull in fig. 172, p. 371, article Monotremata, in 'Todd's Cyclopædia of Anatomy & Physiology' vol. iii. In that skull the postfrontal is named a l i s p h e n o i d.

34. *On the* Skeleton *of a* Theriodont Reptile *from the* Baviaans River (Cape Colony): *Dicranozygoma leptoscelus, gen. et sp. nov.* By Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S. (Read June 20th, 1900.)

[Plate XXXVI.]

The fossil reptilia of South Africa collected or sent to England by the elder and younger Bain became known from isolated fragments, from a mistaken idea (fostered by the published figures) that the skull or the dentition gave information which was of chief scientific interest; but, partly owing to the rapidity with which specimens at the surface become broken and washed away when exposed to the sun and rain, skeletons in a complete state cannot often be obtained; and partly from difficulties of transport in the Karroo Desert, in which they have mostly occurred, associated bones are rarely collected.

In Cape Colony I saw only one specimen showing bones of the skeleton of an Anomodont reptile in natural association. This evidence I now bring before the Geological Society. It had been for some time in the Albany Museum at Grahamstown. The slab containing it is 31 inches long by 10 inches wide. The rock is an extremely hard siliceous sandstone, divided by natural rectangular joints into its present size and form, split so as to expose a portion of the skull, the vertebral column and ribs as far as the pelvis, scapula, part of the humerus, femur, and parts of the tibia and fibula. The skeleton curves over the slab; and has been so divided by the parallel longitudinal joints that the tail and left hind-limb, and apparently part of the right fore-limb, were lost. The bones have decomposed, and are represented by natural moulds. The specimen, slightly distorted by earth-movement and by maceration, was lent to me by the Trustees of the Albany Museum. I brought it to this country, and a beautiful cast, obtained by means of a jelly-mould, was taken from it in the Geological Department of the Natural History Museum, for the Trustees, before the specimen was returned to Grahamstown.

Dr. Schönland, M.A., F.L.S., Director of the Albany Museum, has ascertained for me that the fossil was discovered by Mr. W. Pringle, at about 3400 feet above the sea, upon his property at Ealdon, resting in the bed of the Baviaans River, a tributary of the Great Fish River, flowing south-westward between Tarkastad and Thorn Cross Station. The counterpart has never been known, and was probably swept away by the river before the slab was exposed. Dr. Schönland, however, states that 'there was an additional piece belonging to the animal—I take it to have been the remaining part of the head—which mysteriously disappeared many years ago.'

I have not been successful in my efforts to discover this missing fragment, which is believed to be in a private collection in Paris.

In its absence some uncertainty attaches to the determination of the affinities of the animal, although enough of the skull remains to show that there are striking features which separate it from all known genera of Theriodontia. It is one of the most important skeletons hitherto found, and is unique in the evidence which it affords of coordination of characters of the dorsal aspect of the more interesting bones.

The Head.

The skull appears to have been about $4\frac{1}{2}$ inches long in the median line; but its greatest length was about 6 inches, owing to the unusual expansion and backward lateral prolongation of the squamosal bones. The greatest width of the skull transversely was in the line of the vertical occipital plate, where the measurement from side to side exceeds $4\frac{1}{2}$ inches.

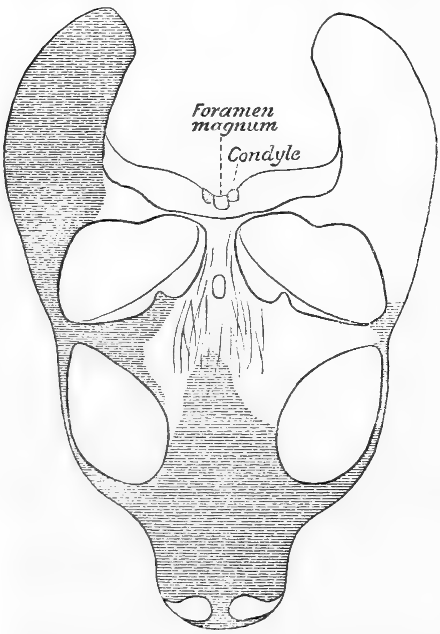
The inner borders of the orbits of the eyes are concave in length, and the least width of the interspace between them exceeds 1 inch. The hinder lateral border formed by the postfrontal bone is preserved on the left side, and has a thickened rounded prominent edge. This triangular bone, narrowing as it extends outward, is concave between its prominent anterior and posterior margins, and makes the anterior limit of the short and wide temporal vacuity. The transverse measurement of the postfrontal is about $\frac{7}{8}$ inch. Its narrow outer edge is directed downward towards the malar region. The space between the postfrontal bones, occupied by the frontal bones, is slightly convex, and is traversed by short elevated longitudinal ridges, which are not parallel but meet so as to enclose long, shallow, fusiform pits, seven or eight in number, in the transverse width of the bones. This ornament is extended backward upon the parietal region; but there is no evidence of it farther forward, because the front of the head is in the missing part of the specimen. This Labyrinthodont type of ornament is known in certain skulls of Theriodonts, but is unknown in *Oudenodon*, *Dicynodon*, or any other South African reptiles with which this fossil may be compared. I have not seen, however, the same net-like pattern in *Cynognathus*, or any Theriodont hitherto described. Behind the postfrontal bones the short parietal region of the skull has slightly concave sides with sharp edges which converge somewhat as they extend backward. The parietal foramen is longitudinally oblong, and about 1 inch in advance of the occipital plate. Immediately behind it the surface of the parietal bones becomes concave.

The occipital plate is nearly vertical, and subtriangular, $\frac{1}{4}$ inch wide at the apex, at the median superior crest of the occiput. This region widens with a narrow concave lateral margin, which excavates a deep wide notch between this triangular plate of the skull and the lateral expansion of the squamosal bone, corresponding to the condition of the narrow edge in the triangular occipital plate of *Gomphognathus*, and corresponding to the deep lateral **V**-shaped notch seen in that genus between that plate and the squamosal region of the zygomatic arch. The width of the base of the occipital

plate appears to be about $2\frac{1}{4}$ inches; it is slightly concave from side to side. The foramen magnum is vertically oblong, and fairly large. On its right side appears to be the right occipital condyle, much less elevated than in *Gomphognathus* or *Cynognathus*, but better marked than in *Lycosaurus* or *Tropidostoma*. Above this region the upper narrow part of the occipital plate leans a little forward, and is slightly concave, as in most Theriodonts.

The squamosal bone is exposed on its inner aspect, very slightly displaced on the left side, so as to be depressed and inclined a little outward in its hinder part, and seen from the inner lateral aspect appears wider than it should be. The malar bone may be carried upon its outer side in the usual way, since it is seen, on the inner side of the zygoma, anteriorly, to form the lateral part of the arch in front of the squamosal bone. This suture is much farther forward than in the known genera of Cynodontia or Gomphodontia, and appears to indicate that the malar bone was relatively smaller than in the better-known Theriodonts. The squamosal has not quite the relations found in Dicynodonts. It is the most remarkable bone of the skull which is evidenced, in being a thin compressed plate prolonged backward behind the occipital crest so as to add nearly one-third to the length of the skull: it is entirely unparalleled. The quadrate articulation is not seen, but on the right side is a fragment of a squamous bone descending below and behind the quadrate region, which may be a further expansion of the quadrate bone. Its inferior edge is rounded; the posterior border is broken. The visible surface of that part of the squamosal which forms the outer hinder boundary of the zygomatic arch has a convex external contour, which becomes rounded behind, and is then reflected upward on the inner or occipital edge. The bone terminates in front below the level of the

Restoration of Skull of Dicranozygoma leptoscelus, *gen. et sp. nov.* ($\frac{1}{2}$ *nat. size*).



[The shaded portions are those not preserved in the actual specimen.]

summit of the postfrontal arch to the orbit, as a thin bar external to the relatively small malar bone. Its extreme length exceeds 3 inches. The short temporal vacuities are half as wide again as long, but are inclined obliquely outward and forward; while the orbits must have been directed obliquely inward and forward. On these data I have restored the skull in the accompanying figure (p. 648), basing the form and length of the snout on known characters of allied reptiles.

The Vertebral Column.

The total length of the vertebral column, as preserved, is 18 inches from the occipital plate to the last sacral vertebra. It extends in a curve convex towards the right side—which has had the effect of crushing the dorsal ribs together, so that they are all turned upward on the right side to expose their external edges and vertically-convex contour, corresponding to the natural curvature of the side of the animal. On the left side the ribs are pressed flat in the usual way, curving outward so as to expose their posterior aspect.

In the middle part of the column the specimen showed a natural mould of the neural canal, and this, in the relief-cast, is now shown as a canal, remarkable for its width and depth, which diminishes somewhat in size as it extends backward. This preservation of the neural canal is the cause for the imperfect exhibition of the forms of the neural spines of the dorsal vertebræ, which could not in all cases be completely cleared in the anterior and middle portions of the column, though I endeavoured to show the forms of several on the right side of the slab.

The cervical region has suffered from the effects of one of those explosions which so frequently disturb the natural relations of bones after death, so that the vertebræ are scattered, and the number of cervical vertebræ cannot be given with certainty. Effects of this disturbance are also seen in the curvature of the backbone, the condition of the skull, and other displacements of the bones.

I am unable to recognize more than six cervical vertebræ, which are all scattered and imperfectly exposed. One of these, having the centrum more than $\frac{1}{2}$ inch long, exposed laterally, shows the articular face of the centrum; it is transversely ovate, $\frac{5}{8}$ inch deep, $\frac{7}{8}$ inch wide, and is concavely cupped, exactly like the centrum of *Anthodon*. This fish-like form of articulation is the more interesting, because there has hitherto been no evidence of it in the centra of South African Theriodonts. The vertebra which is hindermost in position appears to have flattened blade-like ribs which are convex in front, straight behind, $\frac{1}{2}$ inch wide, and three to four times as long. The neural spines in the neck are vertical, but do not appear to have been elevated. The scattered neck-vertebræ are on a slightly lower level as compared with the dorsal vertebræ, which are in continuous sequence. But the earliest of these vertebræ are depressed out of sight, together with the earlier ribs of the left side, the scapular arch, and limb.

Twenty-one vertebræ in advance of the ilium are indicated by

ribs. On account of its extreme shortness the earliest rib, less than $2\frac{1}{2}$ inches long, may belong to the neck. The fifteen which follow may be counted as dorsal, and the four which succeed them may be regarded as lumbar, the ribs being practically absent, as in mammals, from the lower part of the back, where they do not enclose the abdomen as in reptiles.

The dorsal ribs gradually become longer, from about 4 inches in the earliest to 6 or 7 inches at the tenth or eleventh ; but then they diminish in length again, and the last dorsal rib is 5 inches long. The transition is abrupt to the short ribs of the lumbar series. The ribs of the back are strong, rounded from back to front, compressed from side to side, with a shallow longitudinal groove running along the posterior surface of each ; the anterior surface is not exposed. Each rib diminishes in depth towards its extremity, but the width remains unchanged. One specimen appears to show that the rib is hollow or cancellous at the fractured extremity. The curvature of the ribs is remarkably small, and in contrast with Plesiosaurs and Ichthyosaurs, a character which appears to indicate that the cavity of the thorax was deep in proportion to its width. There is no trace of sternal or abdominal ribs preserved; and *Mesosaurus* is still the only South African reptile in which abdominal ribs are known.

The articular head of a dorsal rib shows no indication of separation into two distinct facets. It is expanded a little from side to side, convex or angular from above downward, and is produced somewhat proximally. In the earlier ribs it is $\frac{1}{2}$ inch deep. The effect of the form of the proximal rib-facet is to produce a small emargination of the rib superiorly, external to the articulation, which truncates the rib obliquely. Its upper part articulates in the early dorsal vertebræ with the transverse process, and the lower part articulates apparently with the centrum of the vertebra. The two articular facets are not clearly seen on the side in any vertebra, and it is possible that the lower or capitular part in the early vertebræ may be between the centra, as in *Cynognathus* and *Mesosaurus*. These ribs are generally similar to those of the small *Herpetocheirus brachycnemus*, a Theriodont which I found at Klipfontein, near Fraserburg.[1]

The first lumbar or last dorsal rib is $3\frac{1}{2}$ inches long as preserved, but may be an imperfect dorsal rib, being similar to the dorsal ribs in position and curvature. But the four succeeding lumbar ribs are each about $1\frac{1}{2}$ inches long, more cylindrical, uniform in character, directed more transversely outward, a little curved at the proximal end which is compressed from side to side, and deep as in the dorsal region.

The bodies of the dorsal vertebræ are very partially exposed. They are at first less than $\frac{1}{2}$ inch long, and gradually increase in length, so that the last dorsal or first lumbar centrum is $\frac{3}{4}$ inch long. At first the bodies of the vertebræ, as exposed in the large

[1] Phil. Trans. Roy. Soc. vol. clxxxvi (1895) B, p. 158 & fig. 4.

neural canal, are seen to be in close contact one with the other; but in the middle and lower part of the back there are interspaces between the adjacent centra, which I regard as indicating probably the existence of intercentra in that part of the vertebral column. A similar condition is seen in *Cynognathus* and *Pareiasaurus*, when intercentra are developed on the visceral surfaces of the vertebræ. The interspace between the centra appears to be least at the base of the neural canal, and to augment laterally, permitting a large amount of lateral curvature of the body. Four vertebræ extend over $3\frac{1}{4}$ inches.

The neural arches are at first small. The neural spine is small, vertical, strong, wedge-shaped, sharp in front, flattened behind, terminating downward in a close-set V-shaped pair of post-zygapophyses. The transverse processes are given off at the base of the neural spine and directed outward, slightly upward, and backward, rounded from front to back, where the measurement is $\frac{1}{4}$ inch, and expanded at the extremity, which is not unlike the corresponding surface in an Ornithosaur. The articular face for the rib looks downward and outward on its inferior surface. The transverse measurement over the processes in an early dorsal exceeds 1 inch.

Only two early dorsal vertebræ have the neural spines preserved. They are followed by eight from which the neural spine and roof to the neural canal is lost. Thus there is a marked contrast between the aspect of the early dorsal and lumbar vertebræ, in which the upper part of the neural arch is preserved, due to the circumstance that the transverse processes rapidly become shorter, and disappear by ascending the side of the neural arch and becoming an oblique, sharp, lateral ridge which extends upward and backward, fully $\frac{3}{4}$ inch long, terminating in a prominent rounded tubercle (external to the post-zygapophyses) which has no relation to the rib. These processes form practically the oblique sides of the neural arch, and become merged in the neurapophyses, with the oblique facets of the zygapophysis between them in front and behind. The pre-zygapophysial facet has become much larger than in the early vertebræ, but still looks inward and upward. The neural spine, instead of being elevated and free, has become flattened, and forms the median ridge of the neural arch, which has become nearly horizontal, with the two flattened sides sloping outward from it. It terminates backward in a median point, and the lateral areas are widened a little at the posterior angles by the post-zygapophyses. The last lumbar vertebra has this superior part of the neural arch shorter, and the median ridge is more elevated.

The sacrum is entirely hidden beneath the iliac bones. I suppose that there may have been four sacral vertebræ, because the length (3 inches) corresponds to the length of the four lumbar vertebræ. There cannot have been fewer; it is improbable that there are more. The last sacral rib was slender, and less than 1 inch long; the first is more than 1 inch long, and not stout. The last shows an expansion at the external extremity, which articulated with the ilium.

The Scapula.

The right scapula is exposed resting in part upon the early dorsal ribs, its under side being concave, corresponding to their curvature. The bone is $3\frac{1}{2}$ inches long, with a strong humeral articular surface, which is an inch deep and nearly as wide. This thickened condition is prolonged up the posterior edge of the bone, which is convex in length from above downward as well as laterally, diminishing in thickness to $\frac{1}{4}$ inch at its superior termination, forming a distinct ridge along the posterior margin. On this posterior border, a little above the articulation, is a narrow muscular impression about $\frac{3}{4}$ inch long, which is much lower in position than the muscular impression on the scapula referred to *Ptychosiagum orientale* from the Panchet rocks (which may also prove to be a Theriodont), and more like the condition in *Theromus leptonotus*. The bone is constricted above the humeral articulation, and emarginate anteriorly below the acromion-process. The exact amount of the constriction is not shown, owing to the condition of the matrix. Beyond the emargination the bone rapidly widens transversely to 1 inch at the acromion, and ultimately to fully $1\frac{1}{2}$ inches, forming a smooth flattened surface, slightly concave from side to side, with the concavity slightly augmenting as it descends the length of the bone, and ultimately it curves forward on to the anterior side of the bone above the humeral articulation. The superior margin of the scapula is convex from front to back, and moderately thin, like its anterior margin. There is no trace of a spine upon the blade of the scapula, as in most mammals, or as in *Cynognathus*. Moreover, the slab is fractured, so that the blade is not quite perfect, and there are no indications of the other bones of the shoulder-girdle.

The Humerus.

The right humerus was probably 4 inches long, but its proximal end is not exposed, or rather is lost with the longitudinal fracture of the slab. The distal end and part of the radial crest are well displayed; but the bone is inverted in position, so that the radial crest is directed upward.

The crest is compressed, thin, continuous with the radial side of the bone, convex in its lower longitudinal contour, and not extending for more than half the length of the humerus. Below the termination of the crest the shaft narrows to a width of $\frac{5}{8}$ inch, the measurement becoming less as the concave sides approximate in a rounded median convexity which marks the distal disappearance of the radial crest. The thickness of the shaft in this position is about equal to its width. The width rapidly augments by widening on both sides to $1\frac{7}{8}$ inches at the distal end. The external margin of the bone continues thick, though the thickness diminishes to the condyle, and the lateral contour is deeply concave; but on the inner border of the bone its concave lateral contour terminates at $1\frac{1}{4}$ inches from the distal end. Below this point the border becomes compressed and nearly straight, and extends inward beyond the articular

condylar surface, on to which it curves convexly. The epicondylar foramen is similarly situate to that in the humerus referred to *Gomphognathus*, but relatively smaller and elongated, has a wider bridge, and does not extend so far distally. The foramen is partly blocked with a small body wedged into it, which appears to be a small terminal phalange of the foot.

The articular condyles, two in number, are obliquely inclined downward and outward, moderately convex, and defined by a shallow oblique groove parallel to the inner border such that the somewhat flattened inner condyle is nearly twice as wide as the more prominent convex outer condyle, though they are both of somewhat rounded rhomboid form.

The most distinctive feature of the bone is the unbroken concave longitudinal contour of the external border, which is equally unlike *Cynodraco* and *Gomphognathus*, and is more like the isolated humeri which Sir Richard Owen referred to *Dicynodon*.

Resting upon the lower edge of the radial crest of the humerus is a single terminal claw-phalange, presumably of the fore-foot of the same animal. It is strong, $\frac{3}{4}$ inch long, $\frac{1}{2}$ inch wide behind, flattened below, convex above, with the extremity blunt and rounded, and the surface moderately depressed. There are the usual lateral grooves, narrow and faintly impressed; and the curved contour of the posterior border of the articulation appears to be faintly indicated. The claw-digit is better preserved and more elongated than in *Platypodosaurus*, while its blunt extremity is unlike the sharp condition of the claws in *Eurycarpus*. The remainder of the foot is lost with the longitudinal joint bounding the slab.

The Pelvis.

The pelvis is represented by the right ilium, a part of the right ischium, and part of the left ilium. The pubis is only indicated in the acetabulum, and was covered by the ilium. The bones are separate one from the other, and agree in this mutual relation and in form with known Theriodonts; while they differ absolutely from the pelvic bones which have been associated with Dicynodonts, and are usually anchylosed together.

The two iliac bones now lie parallel one to the other, and are pressed nearly flat. They were probably inclined to each other originally at a considerable angle, but still may have met or approximated in the median line. The right bone is $3\frac{1}{2}$ inches long, and $2\frac{1}{4}$ inches in extreme depth in the hinder part over the acetabular wedge, which articulated with the head of the femur. The bone is large and smooth, with its thin superior border forming a semi-ovate contour, most rounded in front, where the bone is reflected slightly outward and upward as in *Platypodosaurus*, on the mammalian plan. The inferior border of the bone from the articular margin of the acetabulum to the anterior angle, is concave in length, rounded from side to side, thickens as it extends backward,

and measures $2\frac{1}{2}$ inches in length in a straight line; this pre-acetabular part of the bone is $1\frac{1}{2}$ inches deep in the middle length of the ilium. Posteriorly, the expanded blade of the ilium terminates in a relatively small wedge-shaped post-acetabular portion rounded at the posterior extremity, which is less than 1 inch deep and more than $\frac{1}{2}$ inch long, defined by an inferior notch: this separates it from the ischiac process which gives attachment to the ischium, and extends equally far back. Hence this post-acetabular process, though similar in form to the posterior process of the ilium in *Cynognathus*, is not closely comparable with it on account of its small size; and because the inferior process, which here stretches from the acetabular part of the ilium to the ischium, has no existence in *Cynognathus*. This ischiac process constitutes the distinctive feature of the ilium in the genus now described.

The width of the inferior acetabular surface of the ilium is $1\frac{1}{4}$ inches. The anterior part is the acetabular articulation, flat below, and at right angles to the expanded blade of the bone; it is convex externally from front to back, with the convexity produced upward and forward on the antero-inferior border of the bone, decreasing in amount as it extends forward. Within the acetabulum, internal to this superior ovate acetabular surface, and separated from it by a slight groove, is an oblique area towards the back of the acetabulum, which extends obliquely downward and inward, and may be a part of the pubic bone; its anterior edge is rounded.

Behind this convex external acetabular surface of the ilium is its flattened compressed ischiac process, extending backward and slightly downward for $\frac{1}{2}$ inch, fully $\frac{1}{4}$ inch deep, and terminating apparently in a nearly square truncated posterior articular surface for the ischium, which is slightly displaced downward. The inferior surface of this ischiac process of the ilium is not articular, though it formed part of the acetabulum.

Only a small portion of the ischium is exposed; it extends behind the ilium as in other Theriodonts. Its anterior articular part is expanded to a large surface which forms the posterior portion of the acetabulum, margined externally by a sharp edge, extending convexly from above downward, measuring $\frac{5}{8}$ inch as it is partly exposed. The thickness of its superior surface for cartilaginous union with the other pelvic bones appears to be $\frac{5}{8}$ inch; whence it may be inferred that the bone is in contact with the pubis. The state of preservation of the specimen affords no evidence as to whether the acetabulum was perforate or imperforate; but if perforate, the perforation must have been small, as in *Cynognathus*.

Behind the articular surfaces of the ischium the bone is compressed to a sharp superior external edge, and is preserved for only $1\frac{5}{8}$ inches of its length. The superior border is gently concave, and the inferior external surface is deeply concave behind the articulation, and is then flattened. So far as preserved, this condition of the ischium is essentially similar to that in *Cynognathus*, and unlike any other animal, though with some approximation to *Microgomphodon*.

The Hind-Limb.

The femur lies with its head just below the pelvic acetabulum, exposing the flattened superior or anterior surface. The bone is 4 inches long, more than 2 inches wide over the proximal end, with the shaft constricted to less than $\frac{1}{2}$ inch in width below the middle of its length, and then widening distally to about 1 inch at the distal articulation. The expanded proximal end is flattened or slightly concave from *post-mortem* pressure, with the superior thin proximal edge convex from within outward as in *Cynognathus*, and to a less degree in *Tribolodon*. But, unlike both these Cynodont genera, the genus now described has no upward reflexion of the trochanter major at the external margin, which is simply the flattened outer extension of the bone; a condition to which the Russian Deuterosauria and German Protorosauria approximate, though in the latter type of Theriodontia the transverse expansion of the head of the femur is small, and the proximal contour is not transversely convex.

The proximal articulation in this genus is well rounded on the inner side of the head, where it is elevated to a distinct convexity on the margin of the inner lateral aspect, as though the bone were carried by the animal more or less horizontally. The proximal edge of the bone on its terminal surface appears to have been slightly convex from side to side, and it recedes from the articular head as it extends outward. The length of the bone on the external side is only 3 inches. The external lateral contour of the femur is necessarily concave. The inner lateral contour is not completely exposed, so that the width of the distal end of the bone cannot be given exactly. It has been crushed, and although $\frac{3}{8}$ inch thick as preserved, it may have been a little thicker. The distal articulation as preserved is not well rounded, and appears to be less rounded than in some of the smaller types like *Herpetocheirus* and *Tribolodon*, but not more than half of the condylar surface is exposed: this has a vertical border on the external margin, rounded at the angles.

The tibia and fibula are in near contact with the distal end of the femur. The tibia only shows $1\frac{1}{2}$ inches of its proximal end; and this is obscured by fracture, which has left enough of the bone-tissue to mask the external form and character in the relief-cast of the bone. As exposed, the truncated proximal end of the tibia is $\frac{3}{4}$ inch wide, and apparently but little wider than the fibula, which appears to articulate with its proximal end by a small surface on the inner side, where the two bones are in contact.

The fibula as exposed is $3\frac{5}{8}$ inches long, but the distal end is partly covered with matrix, so that, although its entire length appears to be shown, it may have been a little longer. The proximal end appears to be convex, and is obliquely truncated like the proximal end of the ulna of a crocodile. It is $\frac{3}{4}$ inch wide, and defined by a sharp edge at the articular margin. The internal longitudinal contour of the bone is concave, and the external border nearly straight to the lower third of its length, where the shaft

appears to curve in a straight bow, and bend a little backward. The external surface of the shaft is flattened proximally, and marked with faint longitudinal lines; the narrow middle part, scarcely more than $\frac{1}{4}$ inch wide, is well rounded, with an appearance of a small longitudinal muscular attachment, below which the bone is flattened towards the distal end, which appears to be thinner than the proximal end, and twisted a little backward. It may be compared with the fibula of *Tribolodon.*

There is no trace of any bone of the tarsus or hind-foot, nor is there any trace of armour.

These remains indicate an animal about 2 feet long, exclusive of the tail, standing probably about 8 inches high, not more than 6 inches wide in the fore part of the body, or more than 4 inches wide in the pelvic region. It must have been an animal of great mobility, capable of easily bending the body; and by straightening the limbs, of occasionally raising its height to 10 inches or more.

Notwithstanding the imperfection of the skull, it may be regarded, from the structure of the head, pelvis, and femur, as a new type of Theriodont reptile, as contributing important facts to the osteology of the group, more especially in regard to the natural association of the bones.

It is possibly to be included in the Cynodontia, from which it differs in characters of the ilium, scapula, and skull, which may be more than generic differences; but I have some slight ground, from fragments picked up on the drift-trail, for suspecting that in *Cynognathus* the tibia and fibula are less unequal in size than they are known to be in *Microgomphodon* and in *Eurycarpus* (which is possibly Lycosaurian). The determination of the exact systematic position of the genus within the Theriodontia, depends upon such evidence as may be obtainable from the missing slab already mentioned, which is reputed to contain the remainder of the skull.

I am indebted to the Government Grant Committee of the Royal Society, 1889, for the opportunity of examining this specimen in Grahamstown; and to the Trustees and Officers of the Albany Museum and the British Museum (Natural History) for facilities in making this record of its structures.

EXPLANATION OF PLATE XXXVI.

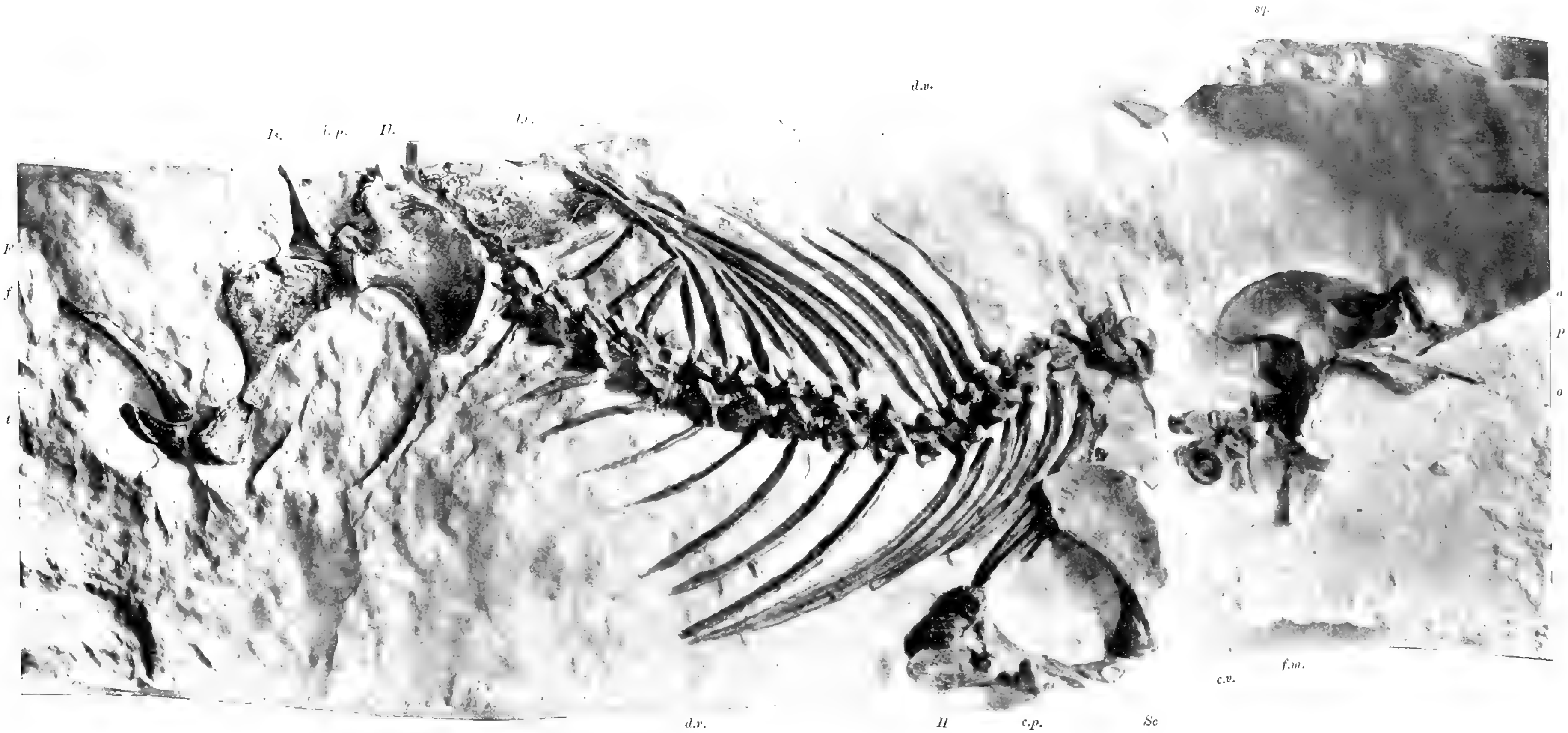
Photographic reproduction of the cast of a skeleton of *Dicranozygoma leptoscelus*, gen. et sp. nov. $\frac{1}{2}$ nat. size.

o = Orbits.
p = Parietal foramen.
f.m = Foramen magnum.
sq = Squamosal bone.
c.v = Displaced cervical vertebræ.
d.v, *d.r* = Dorsal vertebræ and ribs.
l.v = Lumbar vertebræ and ribs.
Il = Iliac bones.
i.p = Ischiac process of ilium.
Is = Ischium.
F = Femur.
f = Fibula.
t = Tibia.
Sc = Scapula.
H = Humerus.
c.p = Claw-phalange.

Discussion.

Prof. Sollas and Mr. Lydekker spoke, and the Author replied.

sq.
l.o
o
p
o
f.m.
c.v.



CAST OF *Dicranozygoma leptoscelus*, gen. et sp. nov. ½ nat. size.

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Vol. LVI. NOVEMBER 5th, 1900. **No. 224.**
PART 4.

Chas A. White

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Wednesday,	November	7–21
,,	December	5–19

1901.

,,	January	9–23
,,	February (*Anniversary*, Feb. 15th)	6–20
,,	March	6–20
,,	April	3–24
,,	May	8–22
,,	June	5–19

[*Business will commence at Eight o'Clock precisely each Evening.*]

35. *The* Igneous Rocks *of the* Coast *of* County Waterford.

By F. R. Cowper Reed, Esq., M.A., F.G.S. (Read May 23rd, 1900.)

Contents.

I. Introductory.

In a former paper on the Waterford coast[1] the Ordovician sedimentary beds and the contemporaneous lavas and tuffs were described. It is now proposed to give an account of the other igneous rocks which occur along the coast, on which I have been at work for the last seven years during repeated visits.

The great complexity of their relations has been noticed by many observers, and while the following account does not claim to be exhaustive, an attempt is here made to determine the order and relations of the principal outbursts of volcanic energy and to describe some of the characters of the rocks.

The bibliography of the Lower Palæozoic rocks of County Waterford has been given in detail in my previous paper. With regard to the igneous rocks, however, the papers by Weaver,[2] Jukes,[3] and Haughton[4] may be referred to, and the accounts by Mr. McHenry & Prof. Watts,[5] and Sir Archibald Geikie[6] may be specially mentioned. The Geological Survey Memoir for Sheets 167, 168, 178 & 179 is a fund of information; and further reference to the igneous rocks will be found in papers by Haughton,[7] A. von Lasaulx,[8] and Dr. Hatch,[9] and in Mr. Teall's 'British Petrography' (pp. 248, 348).

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 718–71.
[2] Trans. Geol. Soc. ser. 2, vol. v, pt. i (1837) p. 1.
[3] Journ. Geol. Soc. Dubl. vol. v (1852) p. 147.
[4] Trans. Roy. Irish Acad. vol. xxiii (1859) p. 563.
[5] Guide to the Collections of Rocks & Fossils belonging to the Geological Survey of Ireland (1895).
[6] 'Ancient Volcanoes of Great Britain' vol. i (1897) pp. 245–51.
[7] Journ. Geol. Soc. Dubl. vol. vii (1857) p. 282.
[8] 'Petrogr. Skizzen aus Irland' Tscherm. Min. u. Petrogr. Mitth. ser. 2, vol. i (1878) p. 446.
[9] Geol. Mag. 1889, p. 545.

The description of the igneous rocks is here given in the first place according to the main petrological types. After having examined the available information as to the relations of these types, we shall be in a position to determine their age and the sequence of events. The rocks of the same petrological type must not be assumed to belong necessarily to the same age. For the investigation of their minute characters over 500 sections of these rocks for the microscope have been prepared.

II. Geographical Distribution and Geological Development of the Rocks.

a. The Felsitic Rocks.

It will be convenient to describe all the felsitic rocks together, though they include many different petrological types and belong to several periods of effusion. Their modes of occurrence, relations, and characters are so various and complicated, that it will be necessary to enter into considerable detail before we can proceed to distinguish their different ages, and classify them into separate groups. In addition to the extensive and multifarious development of the felsites as flows, veins, sheets, and dykes, there are also important masses of tuff and agglomerate with necks, etc. Accordingly the geographical distribution of these rocks will be first described, commencing at the easternmost exposure and thence working westward.

Newtown Head.—At Newtown Head, near Passage, there is a considerable development of intrusive felsite at the base of the Raheen Series. Tongues of a bluish-grey flinty felsite are first seen penetrating the tuffs, etc. of this series, and as they are followed southward they are found to swell out into thick beds, overlying and piercing a mass of diabase.

A small stack of tough, unbedded, felsitic ash stands up on the foreshore, and in the cliffs behind is seen a good section of the vent from which the felsite flowed (fig. 1, p. 659). The diabase near its contact with the felsite is found to be considerably crushed; a narrow crush-zone of soft rotten rock marks the actual line of contact, and can be traced right over the rocks of the foreshore from one side of the vent to the other. In parts the rock is actually brecciated, and there was formerly a section exposed showing large masses of the breccia enclosed in the felsite. In another place a tongue of the felsite was observed protruding into the diabase. The breccia appears to have been formed by the first explosion which drilled the hole through the diabase and associated rocks, the felsitic lava subsequently welling up, filling the pipe, and giving off lateral tongues. The relations of this vent and the felsite make it obvious that this was the latest outburst of volcanic activity at this spot.

Tramore Bay.—Leaving now this locality, and proceeding to the west side of Tramore Bay, we meet with a different development of felsitic rocks. With the exception of a few comparatively

small intrusive masses or sheets piercing the bedded Ordovician rocks —as, for instance, the light greenish felsite near the top of the series in Newtown Cove, and a dyke in Doneraile Cove—the felsites are associated with tuffs, of various degrees of coarseness and containing

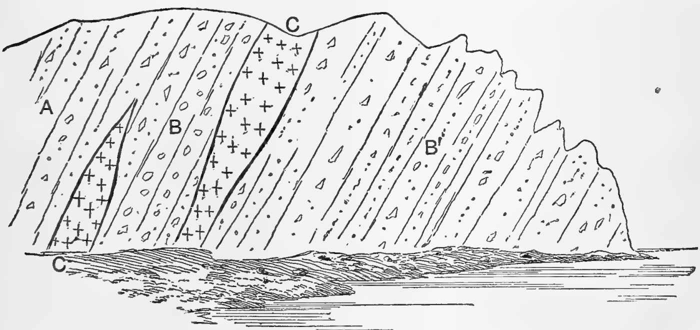
Fig. 1.—*Cliff and foreshore on the south side of Newtown Head.*

A = Dark greenish-grey felsite.

B = Crush-zone, 3 to 8 feet wide.

D = Dark green diabase, partly coarse and partly fine-grained, the varieties graduating imperceptibly one into the other.

Fig. 2.—*The east side of Waterfall Cove.* (*See p. 660.*)



A = Crushed fine felsitic tuff.

B = Very coarse felsitic tuff, indistinctly bedded.

B′ = Scarcely bedded, coarse greenish felsitic tuff, with angular fragments of black slate and of pink felsite.

C = Intrusive sheets of trachytic andesite, altering the felsitic tuffs at the contact.

a large number of fragments of black slate. The first exposure of such a type is met with on the south side of Chair Cove, near Great Newtown Head. It consists of a light greenish-grey, compact and cleaved ash, full of chips of black slate. Associated with it are a

pale-grey banded and perlitic felsite, and another of a darker colour and blotched appearance, which likewise contain xenoliths of black slate.

Great Newtown Head to Garrarus.—West of Great Newtown Head in Ronan's Bay, a tuff similar to that above mentioned has an apparent dip of 70° to 75° north-westward. A series of compact greyish felsites and coarse ashes of similar composition are met with near Little Island, and strike inland to the head of Newtown-Cove Glen, where they are exposed in the fields. Greenish or greyish tuffs of similar character, and apparently bedded, with a steep north-westerly dip, extend westward along the coast to the cove parallel with Hurahan's Rock. On the east side of Waterfall Cove the admixture of many blocks of pink felsite with the slaty fragments is noticeable for the first time in the tuffs, which are here coarser. While the finer tuffs are apparently stratified (fig. 2, p. 659), the coarser portions rarely show any regular bedding, and at the head of Waterfall Cove they pass into an agglomerate wherein the materials are confusedly heaped together. The pink felsitic fragments from this point westward constitute an important element in the tuffs; but in the finer beds on the east they are small and rare.

In the townland of Coolnagoppoge, similar beds are found, being a continuation inland of those on the coast.

The volcanic rocks so far described appear to form a stratified series overlying the Ordovician beds (Tramore Limestones, etc.), with the same general dip. The appearance of bedding is especially evident near Great Newtown Head. Their exact relations, however, cannot be determined; and in the absence of direct evidence from interbedded fossiliferous rocks, we can only say that they are of later date than the youngest proved Ordovician beds. The fragments of black slate have probably been derived from some of these beds; but the original home of the pink felsitic fragments is doubtful, no rocks of this type having been discovered among the Ordovician Series. From the fact that these bedded grey tuffs and felsites have suffered the same disturbance as the fossiliferous rocks, and are pierced like them by many subsequent intrusions of felsite, diabase, dolerite, etc., we may definitely infer that they do not belong to the latest period of igneous activity in this locality. West of Garrarus there are practically no traces of bedding, and xenolithic felsites are very common.

Garrarus.—Proceeding now farther westward to Lady's Cove, Illaunacoltia, we find a scarcely bedded pink felsite, apparently overlying coarse greenish felsitic breccias crowded with pink felsitic fragments. A series of thinly-bedded dark-bluish felsites occurs here at the base of the section, and resting conformably upon them are the coarse greenish breccias with pink felsitic fragments and chips of black slate. Above the breccias comes the pink felsite: this is not of the same type as that of which fragments occur. Several small

faults dislocate the beds in this section, and a vein of later intrusive purplish felsite with glassy margin cuts across them.

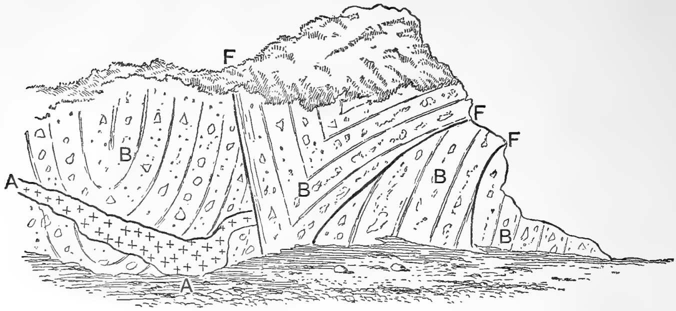
Beds of similar character on the strike of these occur inland near the boundary of Garrarus townland. A smaller exposure of bedded volcanic rocks occurs in Lady's Cove, with several thin bands of greenish perlitic felsites; as also a further development of greenish and pink felsites with the usual coarse tuff. A tongue of later greyish spherulitic felsite cuts through the bedded pink felsites, which are considerably disturbed by faults; and a wedge of dark-green perlitic felsite is also let into the midst of the pink felsites by faults. The western point of the cove is formed by a beautiful pink felsite with conspicuous wavy lines of flow, and this rock extends to the eastern end of Garrarus Strand (fig. 3, p. 662), where the greenish tuff and agglomerate (here of extreme coarseness, and containing blocks of pink felsite 2 feet or more in length) set in. The almost complete absence of chips of black slate is here noticeable. Greenish and pinkish felsites of the same type as those in Lady's Cove adjoining are associated here with these agglomerates, and apparently overlie them. The face of the cliffs is, however, considerably obscured by slipped material, and no continuous clear section is visible. But nearer the middle of Garrarus Strand the rocks of these types suddenly cease, and unbedded felsites of a greyish colour and different microscopic character set in (Analysis No. V, p. 679). Their chief feature is, however, the inclusion (fig. 4, p. 662) of large irregular strips and masses of black slate. The relations of these grey felsites to the pinkish felsites and tuffs is not distinctly seen; but it may be either a line of fault or a plane of intrusion, probably the latter. The large slabs and blocks of black slate, often several square yards in area, in the midst of these grey felsites give a marked character to this part of Garrarus Strand.

But these felsites are not all of exactly the same type: some moreover show signs of crushing, and more than one fault shifts them. Their late intrusion appears to be indicated by the inclusion of a mass of diabase which had previously been intruded into the black slates; for everywhere along the coast the diabase-intrusions seem to have been one of the latest manifestations of igneous energy. On the farther side of the western stream similar pale greenish-grey, unbedded felsites, containing small xenoliths, and perhaps belonging to the same set of intrusions, are exposed.

West of the central promontory, marked '125' on the 6-inch Ordnance-Survey map, in the middle of Garrarus Strand, intricate and confused sections in the cliffs are seen showing numerous irregular tongues of the cryptocrystalline greenish felsite branching off from the main mass, and piercing the black slates. A dyke of a light-grey horny felsite of microcrystalline structure is also exposed.

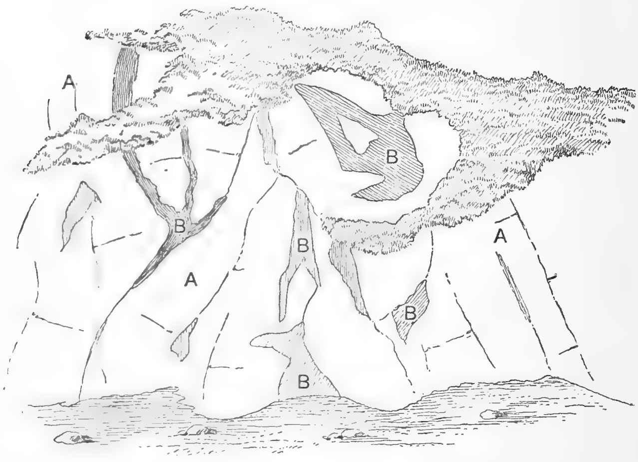
Another rock (fig. 5, p. 662), which here requires mention, forms a low boss at the foot of the cliffs, consisting of a peculiar type of felsite-porphyry, and apparently later than the main mass of felsites, though it is pierced like them by small veins of greyish opaque trachyte.

Fig. 3.—*Garrarus Strand, north-eastern corner.* (*See p. 661.*)



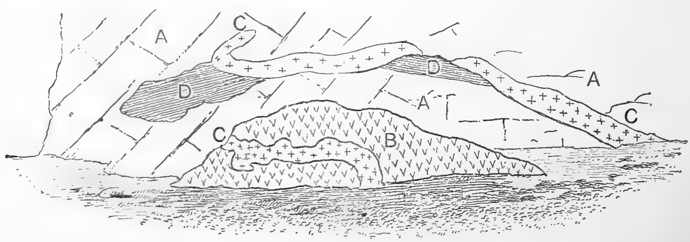
A = Intrusive vein of trachyte. FF = Faults.
B = Greenish volcanic agglomerate, varying in coarseness, and containing numerous subangular fragments of pink felsite : bedding indistinct.

Fig. 4.—*Centre of Garrarus Strand.* (*See p. 661.*)



A = Greyish felsite enclosing large strips and blocks of black slate (B).

Fig. 5.—*Base of cliffs, western end of Garrarus Strand.* (*See p. 661.*)



A = Dark greenish cryptocrystalline felsite.
B = Felsite-porphyry.
C = Pale grey trachytic veins.
D = Included patches of black slate.

Sheep Island.—Greenish felsites of the same general type, and containing small xenoliths of pink felsite and black slate, continue westward to the small strand near Sheep Island, where a vent is situated on a projecting point, about 200 yards east of the spot marked 'Boatstrand' on the 6-inch Ordnance-Survey map. The eastern side of the vent is formed by the greenish felsite, with a boss of grey horny felsite rising up into it. The agglomerate filling the vent consists of fragments of greyish felsite, some measuring 2 or 3 feet in diameter, and cemented together by a pale greenish-yellow matrix. A green felsite resembling this matrix is intimately associated with this agglomerate, having been extruded into it and around it.

The whole headland running out to Sheep Island is extremely complicated, and exhibits a group of closely-packed vents with felsites, tuffs, and agglomerates. A green felsite enclosing large fragments of black slates, and betraying evident signs of considerable crushing, is exposed at the waterfall. This is faulted against a non-xenolithic pink felsite; and the western side of the extreme point of the headland shows a section where the pink felsite is seen in contact with a coarse dark-greenish ash or agglomerate, crowded with fragments of a similar pink felsite. The line of contact is nearly vertical, and along it the ash is bedded, but probably this pseudo-stratification is due to pressure. A stack of similar ash occurs on the foreshore, with fragments of a more reddish felsite in it. The agglomerate at one point near the base of the cliff consists almost entirely of huge blocks of a pink felsite, and a large mass of black slate is also a conspicuous object in the middle of it. It appears that reddish and pink felsites were first extruded and consolidated, before the violent explosion took place which shattered them and filled the pipe with their remains. The pink felsite was then injected into the agglomerate. The green tuff passes laterally into less coarse and better compacted tuffs, associated with a special type of felsite crowded with xenoliths, which extends almost uninterruptedly to Annestown Bay.

A fragment of the reddish felsitic outflow is preserved in a needle-like stack close by on the foreshore, and its character corresponds to that of the fragments in the green tuff.

A later phase of volcanic activity is represented here by a pipe filled with a slightly compacted breccia of greyish felsite, associated with the solid grey felsite breaking through the green tuffs and xenolithic felsites. The latter gradually lose most of their xenoliths as we follow them westward, and some of the associated flows, resembling them macroscopically and microscopically, are quite free from any inclusions. Sporadic patches of very coarsely xenolithic rock occur, perhaps pointing to subsidiary vents or to an intermittent violence in the eruptions.

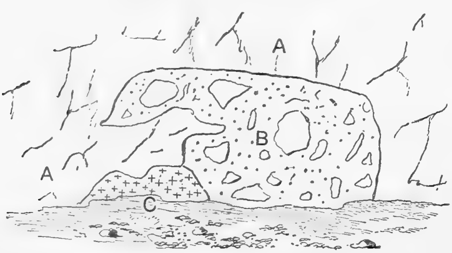
Kilfarrasy.—Yet farther west, at the point called the Black Door, by Kilfarrasy Strand, the greenish xenolithic felsites are still met with, and show a rude kind of bedding with a south-south-

easterly dip of 60° to 70°. The fragments of black slate are here more numerous than those of pink felsite. Between these felsites and the extensive exposure of contorted black slates on this strand occurs a mass of brecciated greyish felsite, in a soft crumbling or greasy matrix of the same nature containing small chips of the black slate. This mass, which is exposed all the way up the face of the cliff, may represent an old pipe.

The relations of the black slates to the intrusive greenish felsite in the middle of Kilfarrasy Strand have been described and figured on a previous occasion.[1] This greenish felsite is full of pieces of the black slates, and the cliffs consist of it for some 50 yards west as far as the faulted-in mass of Tramore Limestones (*op. cit.* fig. 11, p. 734). Beyond this mass the intrusive nature of the felsites into the slates after they had received their cleavage is very evident; and the irregular tongues and veins of felsite in the main mass of Tramore Limestone are of the same petrological character, and belong probably to the same group of intrusions. The different characters of these Kilfarrasy felsites make it appear probable that they do not belong to exactly the same vent or group of vents, or perhaps not to the same period, as those containing the numerous pink felsitic fragments previously described. They have suffered also much more from crushing and faulting.

Passing now to the western side of Kilfarrasy Island, greenish felsites of the same character without any discernible bedding are found, penetrated by a sheet of beautifully columnar pinkish felsite. A great sheet of diabase, subsequently described (p. 673), also pierces them together with the greenish felsite and tuffs with pink xenoliths, which again set in and continue westward as far as Annestown. There is evidence also of a slightly later felsitic eruption in the shape of an irregular sheet of banded greenish felsite, which cuts across the other acid rocks, but is earlier than the diabase and has brecciated margins. At one spot which suggests a vent, there is a mass of breccia of this rock enwrapped and almost enclosed by felsite of the same character; some of the blocks in this breccia measure 4 feet in length (fig. 6). At another neighbouring point there is also an indication of the site of one of the vents of the earlier pink and

Fig. 6.—*Base of cliff between Kilfarrasy Island and Annestown.*



A = Greenish banded felsite.
B = Mass of coarse breccia of the same felsite.
C = Vein of grey trachyte penetrating A & B.

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 734 & fig. 10.

greenish xenolithic felsites forming the greater part of the cliffs, in the shape of a sudden increase in the coarseness of the materials so as to form an agglomerate, about halfway between Kilfarrasy Island and Green Island. It is, moreover, noticeable that some of the lava-flows from vents of this age were all but entirely free from xenoliths, though most of those of such a character are of the nature of dykes or veins of later date.

Annestown.—The whole of the cliffs around Annestown Bay are composed of the widespread pink and greenish xenolithic felsites, exhibiting the usual characters and possessing no distinct bedding; but they suddenly come to an end opposite Carrickadurrish Rock at the eastern end of the adjoining Morageeha Strand, being abruptly broken off against a group of felsitic rocks, of a totally different character, surrounding a small vent.

Before proceeding further, it may be convenient to review briefly the distribution and development of the foregoing important type of felsitic rocks. The occurrence of clastic volcanic rocks with pink felsitic fragments is first noticeable at Waterfall Cove opposite Hurahan's Rock. It is the easternmost exposure of this type on the coast, and by the coarseness of the materials at this spot the proximity of a vent is suggested. Several other probable sites of vents ejecting similar materials between this point and Annestown have been described, but the chief exposure of pink felsitic lavas associated with these tuffs and agglomerates is observed near Garrarus, where also greenish felsites belonging to the same period of eruption are developed. It is difficult to say definitely whether the bedding occasionally observable in this group of rocks is real, or only apparent, or superinduced. At any rate, evidence is afforded by the slight local variations in character and development, as the rocks are followed from east to west, that more or less irregularity exists in the succession: indeed it is doubtful whether any definite succession is traceable. The presence of a syncline between Hurahan's Rock and Kilfarrasy seems to be suggested by the dip of the beds, so far as it is shown. It is a remarkable fact that no fragments of the greyish felsites and tuffs near Great Newtown Head have been recognized in this series: that it belongs, nevertheless, to a later period of volcanic activity appears in the highest degree probable.

The grey and pale greenish felsites which are well developed in the centre of Garrarus Strand belong to another outburst, and are of quite a different type of rock. Moreover, they are not associated with any fragmental beds, and in no place do they contain any fragments of pink felsite. Their characteristic feature is the inclusion of large masses and irregular pieces of black slate. Probably belonging to this stage of eruptivity are the vents with greyish felsitic materials near Sheep Island, and the other at the Black Door, Kilfarrasy. As these pipes of felsitic material pierce the pink and greenish xenolithic felsites and tuffs of the other series above described, we have reason to believe that they are of later age.

The felsites of the whole of Kilfarrasy Strand belong not improbably to the same late period.

Such are the principal groups of felsitic rocks, but we have also to notice the more isolated and differentiated occurrences, and must make an attempt to fix their relative ages. Thus the beautiful columnar sheet of pink felsite of Kilfarrasy Island is obviously still later than the felsites which it pierces, and these themselves belong to the latest group above mentioned. Perhaps the tongue of purplish felsite in Lady's Cove, Illaunacoltia, is of the same age as this columnar sheet. The felsite-porphyry at the western end of Garrarus Strand is also probably one of the later intrusions (see p. 676).

Morageeha and Knockane Strands.—We may now proceed to notice the felsitic rocks west of Annestown. The group of felsites at the eastern end of Morageeha Strand comprises various types, but they are all associated with a crushed greyish felsite and tuff filling an old pipe. They send out irregular tongues and protrusions into the surrounding rocks, and enclose portions of the black slates which bound them on the west. These black slates, which dip generally north-westward at high angles and are excessively cleaved, were penetrated by several irregular sheets or dykes of felsite subsequent to their crumpling and cleavage. The large detached rock called the Long Rock, near Knockane Strand, consists of a massive grey felsite which is also exposed in the cliffs behind; and the shattered condition of the neighbouring slates shows that it has burst through them. A large mass of grey quartz-porphyry is here inserted in the midst of this grey felsite, though its relations are not seen with distinctness owing to landslips; but it seems to represent the central plug in the pipe up which the grey felsite welled. The latter is seen to enclose large blocks of the black slate on its western boundary, and the massive sheets of similar felsite that occur on the adjoining promontory separating Knockane from Morageeha Strand, and show similar relations to the black slates, are probably apophyses of it. There is a small vent situated just here, consisting of a plug of grey felsite, of the same type as that of the Long Rock, surrounded by a zone of brecciated slate measuring in places as much as 12 feet in width. This mass of closely-packed fragments of slate has suffered a rude sort of cleavage with the surrounding slates, in consequence of movements subsequent to the explosion which blew out the vent and filled the pipe with breccia; but since the felsite itself shows no sign of crushing, these movements must have occurred prior to its injection into the pipe.

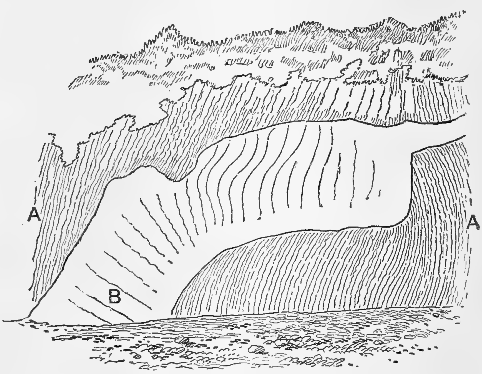
Immediately west of this occurs a sharply-defined and nearly vertical dyke of dark-grey felsite, with regular parallel walls and of a different petrological type, traversing the slates. Two more masses of felsite considerably shattered are found between this spot and Dunabrattin Head, on the western side of which occurs the large boss of horny grey felsite intruded into the base of the Tramore Limestones and previously figured.[1]

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 736, fig. 14.

Kilmurrin Cove.—In this cove there is an interesting group of rocks: strongly-cleaved green felsitic tuffs, mostly of coarse texture, stained red in parts, and containing numerous fragments of a microgranular felsite, are pierced and overlain by veins and apophyses of a diabase, which in its turn is pierced by a dyke of banded felsite. Owing, however, to the unfortunate inaccessibility of the adjoining cliffs the further relations of these beds cannot be determined. It is plain that they belong to a type not elsewhere met with along this coast.

Foilnaneena Cove.—At this cove, in the townland of Tankardstown, we find a volcanic neck of felsitic materials, chiefly fragments of the adjoining felsite-porphyry. This seems to have burst through a group of earlier igneous rocks which resemble trachytes or bostonites. A dyke of banded felsite like that at Kilmurrin Cove cuts through all these rocks. The purplish slates between this spot and Knockmahon are pierced by several sheets and dykes of felsite. There is also an intrusive sheet of felsite-porphyry. One of the felsitic sheets shows well-developed columnar jointing, with the columns mostly straight and at right angles to the bounding surfaces, but somewhat bent in one part (fig. 7). Another sheet, which is exposed in the cliffs, also forms the upper portion of the prominent stack called Cassaunagreana Rock. But the finest and largest sheet of felsite showing columnar jointing is that known as the 'Bishop's Library.'[1] It is at least 100 feet thick, and the columns, which are from four to six-sided, are arranged in tiers at right angles to the bounding surfaces of the sheet. It is by far the most conspicuous example of columnar jointing along the whole Waterford coast.

Fig. 7.—*Sheet of columnar felsite intrusive in light purplish slates, in the cliffs between Cassaunagreana Rock and Foilnaneena Cove, near Knockmahon.*



A = Light purplish slates, crushed and slightly altered at the junction with the intrusive sheet.
B = Felsitic sheet with columnar jointing. In one place the columns are bent.

Knockmahon.—Near the faulted-in block of Tramore Limestone, below the engine-house at Knockmahon, occurs a shattered

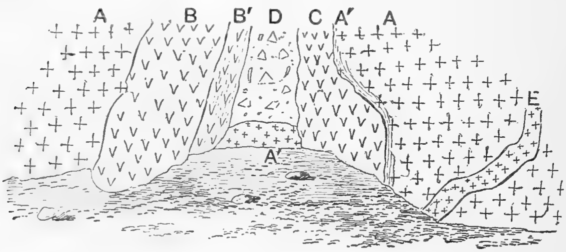
[1] Haughton, Journ. Geol. Soc. Dubl. vol. vii (1857) p. 284.

felsite earlier in date than the formation of the faults,[1] but whether it is of the same date as the above-mentioned sheets is difficult to determine. On the farther side of it is a mass of tough greyish felsite-porphyry, not unlike that at Foilnaneena and the Long Rock, and forming most of the small headland by the Wooden Jetty; but it is pierced and overlain by felsites of more than one type, which are themselves affected by the faults on each side of the block of limestones.

The relation of the red sandstones, etc. to the igneous rocks is well seen here, one of these felsites ending up abruptly against them; and a decided unconformity exists between the two series.[2]

In the succession of small coves between this spot and Bunmahon Bay are seen two narrow dyke-like intrusions of felsite-porphyry, with a vertical mass of brecciated material of the same character sandwiched in between them. The enclosing walls are of purplish augite-porphyrite, and are much shattered and baked along the planes of contact. Probably we have here an old felsitic vent (fig. 8). Some apophyses of felsite, most likely connected with the same outburst, pierce the surrounding more basic rocks.

Fig. 8.—*Cove between Knockmahon and Bunmahon.*



A = Purplish augite-porphyrite.
A′ = The same, shattered.
B = Dark green felsite-porphyry, intrusive in A.
B′ = The same, shattered.
C = Paler green felsite-porphyry, resembling B and intrusive in A.
D = Pipe of breccia of felsitic material.
E = Vein of andesite intrusive in A.

It may be mentioned that on the low-lying hummocky ground immediately east of the bridge over the River Mahon, a low cliff of a pale grey felsite-porphyry, rather similar to that just described in the cliffs, is exposed in contact with, and doubtfully later than, a dark-green diabase.

An extensive development of curious greenish rocks, with dark-green tuffs, and some intrusive veins allied to bostonites, occurs between Bunmahon Village and Bunmahon Head (see pp. 677, 678). None of the ordinary types of felsites have been recognized here on the eastern side of the headland, where the red sandstones and

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 738 & fig. 15.
[2] *Ibid.* vol. liii (1897) p. 281.

conglomerates are faulted against the green tuff (as described on a former occasion).[1] On the west side of the faulted inlier of red rocks this ash is again exposed, and is here penetrated by veins of a greenish microlithic felsite, and by a conspicuous vertical dyke of somewhat decomposed pink felsite, 35 to 40 feet thick. A fault then cuts off this green ash from a small but interesting series of bedded greenish felsites charged with epidote and dipping into the cliff at 30° north-westward. From the fact that they are of the same general petrological type as the felsites associated with the tuff on the eastern side of the head, it is probable that they belong to the same eruption. The lowest bed is a massive, fine-grained, greenish rock, and it passes up into a kind of nodular variety of the same, consisting of concretionary masses, roughly ovoid or subspheroidal, 4 to 8 inches long, and closely packed together, with a whitish shell to each. Above them the rock is of very fine texture, and banded regularly with narrow pale bands, $\frac{1}{8}$ to $\frac{1}{4}$ inch wide, resembling the material that forms the shells of the spheroids. This banded zone is 3 feet thick; above it comes a massive green felsite, similar microscopically to that at the base of the series, and containing obscure traces of the spheroids in its lower portions.

Cooneenacartan Cove.—Leaving now this cove by Bunmahon Head, we find an exposure of felsitic rocks in Cooneenacartan Cove, about 300 yards east of Ballydouane Bay. A greenish felsite forms most of the eastern side, associated with another closely similar felsite, but showing coarse flow-brecciation. At the head of the cove is a coarse greenish ash, containing fragments of green felsite, 'greenstones,' and pink felsite, and bursting through it are several irregular protrusions of purplish and dark-greyish felsites. These felsites appear to be later than the dark-greenish rocks of peculiar character found in this cove (see p. 677), and are of a trachytic type (see § III, Petrological Notes, p. 683).

Ballydouane.—On the eastern side of Ballydouane Bay a dark irregular vein of felsite of considerable width traverses all the rocks except the red sandstones and conglomerates. In the second small cove west of this Bay is the remnant of an old volcanic neck, filled with a coarse felsitic agglomerate and with fragments of the banded calcareous rocks. The neck measures about 16 feet in diameter, at the base of the cliff. Intimately associated with it is a felsite of coarse nodular structure. A pipe of light-greyish felsitic tuff associated with other felsites, but all much traversed by faults, occurs beneath the patch of red rocks in Ballydouane West Bay as described on a previous occasion [2]. All the rest of this bay is bounded by cliffs of greenish felsite, associated with a greenish tuff of similar materials, and traversed by dykes and veins of dark-green felsite of similar type; while high up in the cliffs a vein of bright pink felspar-porphyry, several feet wide, cuts through the other

[1] Quart. Journ. Geol. Soc. vol. liii (1897) pp. 279–80 & figs. 6–7.
[2] *Ibid.* p. 273 & fig. 1.

rocks, but its height from the base of the steep cliffs renders it inaccessible.

That all these felsitic rocks are earlier than the deposition of the red sandstones and conglomerates, is the only fact with regard to their age which can be asserted. All have suffered disturbance prior to the formation of these later rocks.

Killelton Cove.—The greenish felsite of the cliffs seems to consist of a series of superposed sheets dipping eastward at about 30° when we trace them into the adjoining Killelton Cove, where also the coarse greenish ash reappears, though separated from the felsite by a fault. A dyke of dark felsite is here observed cutting the greenish felsite and ash, together with other intrusions; and in the western Killelton Cove (part of which is called Lady's Cove) the green felsite of the cliffs is found in contact with banded black slates. Several dykes of greyish felsite pierce these slates, and are more or less crushed with them. In one spot a mass of coarse agglomerate, containing fragments of the slates, may represent a volcanic pipe.

Ballyvooney Cove.—Until we reach Ballyvooney Cove no other exposures of felsitic rocks occur, the cliffs being composed of black and grey slates, but at this locality a coarse quartz-felsite of later date pierces them, and encloses portions of both the slates and the grey felsites which here reappear.

Stradbally.—The huge boss of so-called greenish felsite extending along the coast for fully ½ mile south-west of Stradbally village has burst through the slates, but appears, from slight variations in its character, to be of composite origin. It is the westernmost of all the felsitic and other acid intrusions along the coast, but its age and relation to them is uncertain, and cannot be directly determined.

b. Necks of Non-Volcanic Materials.

In addition to the pipes associated with the felsitic and basic rocks and filled with fragments of similar materials, there occur some which only contain a breccia of the surrounding rocks and are not connected directly with any of the neighbouring lavas or volcanic ashes. Such is one immediately north of Raheen Bridge (near Passage), where on the foreshore, about 150 yards north of the stream, a small mound about 3 feet high and of somewhat irregular outline, measuring 6 by 4½ feet along its principal diameters, represents an old vent which has been drilled through the surrounding mudstones. The pipe is filled with angular fragments of these beds, and with pieces of black slate and fine-grained sandstone embedded in a greyish paste of slate-dust. No igneous rocks or ashes are observable in connexion with it, and its date is conjectural. In appearance it reminds one of some of the Permian

vents in East Fifeshire, described by Sir Archibald Geikie.[1] That it was formed after the beds which it pierces had received their cleavage is shown by the identical character of the cleaved fragments in the pipe with that of the surrounding solid rocks.

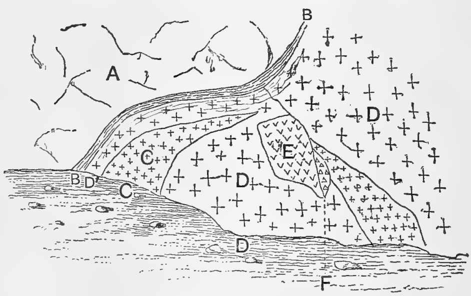
c. The Basic Sills and Vents.

The basic and intermediate rocks of the coast occur principally in the form of large intrusive sheets of diabase, dolerite, or allied rocks, and are sometimes associated with necks composed of similar materials in a clastic condition. These pipes of 'greenstone'-agglomerate represent in some cases the vents from which the flows occurred. There is, however, no evidence that any of these flows took place at the surface, and they all seem to have been forced into or between the older rocks, sometimes along the bedding-planes.

In addition to several large and conspicuous sheets, many smaller tongues and veins of similar or allied rocks are exposed, all of them of late date, but they do not universally belong to the same period of intrusion.

At Newtown Head, Passage, the mass of felsite (fig. 1, p. 659) is distinctly seen to have burst through the diabase and other rocks of the headland, as described on p. 658. The diabase, which first appears at a small spur, down which a path leads to the beach, has broken through the older bedded series (Raheen Series) of felsites and tuffs, and encloses some large blocks of them. It forms a large irregular exposure on the foreshore and at the base of the cliffs, and its margin where it is in contact with the later outburst of felsite is much shattered, crushed, and decomposed.

Fig. 9.—*Section at Newtown Head, showing the relations of the intrusive rocks.*



A = Dark greenish-grey felsite.
B = Crush-zone of D.
C = Intrusive tongues of dolerite.
D = Dark-green coarse diabase.
D′= Crushed diabase.
E = Included mass of pale-grey trachytic andesite.
F = Patch of breccia, consisting chiefly of fragments of E and a grey felsite.

A considerable amount of disturbance has taken place in the mass of the diabase subsequent to its consolidation, but prior to the felsitic eruption. The diabase itself varies slightly in texture, and is

[1] 'Ancient Volcanoes of Great Britain' vol. ii (1897) pp. 73 *et seqq.*

pierced by several veins of fine-grained dolerite of earlier date than the felsite and the accompanying movements (fig. 9, p. 671).

The irregular intrusive sheets which penetrate the Raheen Series nearer Raheen are not of a diabasic nature, and belong apparently to a different and probably earlier series of eruptions. A brief description of them is given subsequently.

Turning now to the neighbourhood of Tramore, we find one of the principal and most extensive sheets of diabase in the district exposed more or less continuously in the cliffs on the western side of the bay. It has been intruded for the most part along the junction of the Tramore Limestone and the underlying Tramore Slates, but it frequently crosses the bedding-planes of both.[1] It is, moreover, later than the movements which have affected their relations and cuts across most of the faults and thrust-planes that traverse them; but the transverse faults which occur between Tramore village and Great Newtown Head shift the diabase as well as all the other rocks. It preserves the same general petrological characters for its whole course, and fails to produce any marked contact-phenomena in the adjacent rocks. None of the other intrusive rocks pierce it.

A few yards north of Lady Elizabeth's Cove is the well-known neck which was figured by Du Noyer in the Survey Memoir,[2] but was described by him as a 'fissured greenstone-dyke.' This neck consists of a dyke-like mass of dark-green coarse tuff, about 12 feet in diameter at the base, and running obliquely up the face of the cliff through the diabase, with sharply defined margins. The Tramore Limestones occur on the beach in front, dipping north-westward at 60°. The tuff is entirely composed of fragments of the surrounding diabase embedded in a finer matrix of the same nature. It is thus evident that this pipe was drilled after the intrusion and consolidation of this sheet of diabase.

A parallel sheet of a slightly different petrological type is seen in the fields adjoining the cliff-road between Lady Elizabeth's and Newtown Coves, and near the top of the fossiliferous series in the latter cove another sheet is exposed.

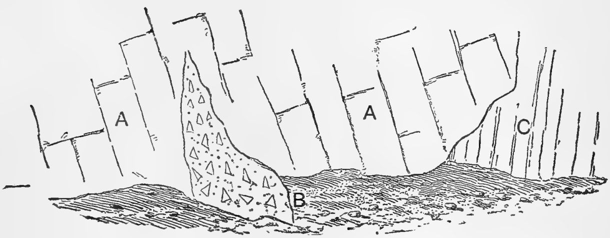
On the south side of Oonagappul, and in Chair Cove near Great Newtown Head, a sheet of diabase—probably a continuation of one of those above-mentioned—is found cutting across the felsites, and passing between the 'Metal Man' and the eastern tower on the headland, to reappear in the cliffs opposite the Stag Rocks, which it probably forms. The southernmost point of the Head is composed of a dark, compact, and fresher-looking dolerite.

All the foregoing diabases or dolerites are of the nature of sheets following more or less regularly the strike of the beds; and all the evidence points to the conclusion that they are the latest igneous intrusions along this part of the coast.

[1] See Quart. Journ. Geol. Soc. vol. lv (1899) figs. 2, 3, 5, 6, & 8, pp. 725 *et seqq.*
[2] Mem. Geol. Surv. Irel. 1865, Explan. Sheets 167, 168, etc. fig. 5, p. 54.

On both sides of Ronan's Bay diabase is again found piercing the felsitic rocks, and probably is the end of a similar sheet. It leads on to a small neck of coarse greenish tuff composed principally of fragments of diabase, situated near the edge of the cliffs north of Little Island. The outline of the neck, which measures several yards in diameter, can be traced in the grey felsites and felsitic tuffs through which it bursts, and it appears to be of similar character to that near Lady Elizabeth's Cove. Little Island itself consists of an ophitic dark-green diabase which bursts through the felsitic rocks, but has suffered in places much crushing; and in the small cove west of this island another mass of slightly different type rises up through the same rocks, and also is seen to truncate earlier intrusive veins. Another vent seems to be present on the promontory called Great Island, about $\frac{1}{4}$ mile farther west, where a mass of diabase-tuff is exposed, associated with an intrusion of solid diabase, as in the other instances.

Fig. 10.—*Section at the base of the cliffs on the west side of Kilfarrasy Island.*



A = Sheet of intrusive diabase, showing columnar jointing.
B = Patch of diabase-agglomerate, representing a neck.
C = Greenish felsite, altered.

The finest example of a diabase-sheet along the whole coast is found on the west side of Kilfarrasy Island, where, close to the waterfall, a great mass of dark-green diabase is seen breaking through the greenish felsites which are intrusive in the black slates. A portion of a neck of diabase-agglomerate is completely enwrapped by the sheet, and probably marks the position of the vent or of one of the vents connected with it (fig. 10). Rude columnar jointing is noticeable in this sheet of diabase, which is exposed, with only one small interruption, for fully 300 yards continuously along the face of the cliffs, ending about $\frac{1}{2}$ mile east of Green Island. That it was intruded into the green felsites and felsitic tuffs is plainly shown at its western extremity. In the Geological Survey Memoir [1] this sheet is called the Whitefield Greenstone. It is the westernmost of the large sheets of diabase; and the somewhat similar rocks which occur along the cliffs to the west are of a different macroscopic or microscopic appearance, do not form masses so extensive, have frequently suffered considerable

[1] Mem. Geol. Surv. Irel. 1865, Explan. Sheets 167, 168, etc. p. 55.

mechanical disturbance with the surrounding rocks, and are themselves in several cases penetrated by later intrusions.

d. Intrusions of Dolerite.

Not many intrusions of true dolerite occur along the coast, most of the dark-greenish rocks which resemble them at first sight proving to be decomposed keratophyres. The true dolerites occur mostly as small irregular veins or tongues, and rarely as dykes.

At Newtown Head (fig. 9, p. 671) it has been remarked that irregular veins of fine-grained dolerite penetrate the coarse diabase of the headland. Some of the veins might be termed andesitic dolerites, but all are earlier than the felsite which breaks across them. Most of the other irregular intrusions that traverse the bedded Ordovician rocks in this locality are much less basic in character, and must be classed with the trachytes or andesitic trachytes.

From here we may pass to Knockmahon, where a complicated group of intrusive veins and irregular sheets of dolerite and diabase is exhibited in the cliffs and series of small coves between the villages of Knockmahon and Bunmahon. Several more or less distinct varieties of these rocks, sometimes with columnar jointing, are here present, and their mutual relations are intricate; but they apparently belong to one general period of eruption which is certainly later than that of the augite-porphyrite and purple slates (see p. 677), both of which they pierce (fig. 8, p. 668). I do not think that this group of intrusions belongs to the same category or age as the great diabase-sheets to the east. Rather would I look upon it as a recrudescence of the local igneous activity which first led to the extrusion of the augite-porphyrite; and we know that it occurred earlier than the formation of the felsitic vents and dykes at this spot, since the latter pierce all the other rocks.

e. The Smaller Intrusive Veins.

There is a widespread development of irregular intrusive veins, mostly of small size and in a decomposed condition, which have been injected into the felsites, etc. prior to the formation of the basic sills just described. In many cases the original characters of these rocks are extremely indistinct, and their true nature can with difficulty be made out, or remains uncertain, owing to their advanced state of decomposition and the abundance of secondary minerals. The majority are pale-grey or greenish-grey in colour, with a rough irregular fracture, and are easily distinguishable from the felsites by these features, as well as by their behaviour in the field.

Several definite petrological types are distinguishable, and though at first they were all provisionally assigned to the andesites, it has been found that they are mostly more acid in character. Some of the veins, by their dark-green coloration and macroscopic appearance, resemble even dolerite, but many of these are probably keratophyres, and their microscopic characters support this view. The majority appear to be rather trachytes or andesitic

trachytes, and some resemble closely the so-called bostonites. The separation of these various types in the field is practically impossible, but the examination of a large number of microscope-sections has revealed their true characters. It is not improbable that they do not all belong to precisely the same date of intrusion: some may be slightly earlier than others, but the whole group appears to be later than the felsites and earlier than the basic sills, earlier perhaps than many of the felspar-porphyries. The sedimentary Ordovician rocks are abundantly pierced by them, but they are affected by most of the faults which traverse the area, and the manner in which they are shifted and displaced by them is illustrated at many points along the coast.

At Newtown Head, Passage, several large intrusive tongues and irregular veins belonging to this group pierce the bedded rocks, and they seem to be of a trachytic nature from their microscopic characters and chemical composition (see p. 685). Two of these intrusions measure each from 50 to 60 feet across, as exposed on the foreshore. The others are of smaller size, and in some cases have vesicular margins. That some at any rate of these are earlier than the diabase of the headland is shown by the inclusion of a portion of a vein by the latter. (See fig. 9, p. 671.)

Between Tramore and Great Newtown Head are many intrusions of this group. Some of them are of a glassy nature, and have suffered contortion and crushing with the Tramore Slates.

Two true dykes of a light-grey trachytic aspect pierce the Tramore Limestones and bedded felsites, at right angles to their bedding, near Doneraile Cove; and on the south side of this cove is a considerable development of irregular veins of what appears to be a much decomposed andesitic trachyte. A sheet of similar character occurs among the felsites on the north side, and a larger tongue extends over the foreshore near the base of the Tramore Limestones. Of the same type are those piercing the same beds near Fish Cove and above Oonagappul; but those in the coves opposite Carrigaghalia penetrating the *Dicranograptus*-shales are paler in colour, and show different microscopic characters.

The sheets in the felsitic tuffs in Waterfall Cove belong rather to the trachytic andesitic type, and are of a darker colour (fig. 2, p. 659). A dyke of pale-grey trachyte occurs in Lady's Cove, Garrarus, and veins of a similar nature penetrate the felsitic tuffs and agglomerates at the eastern end of Garrarus Strand. A peculiar banded variety is found at this spot. Several small veins of a closely similar nature pierce the black slates in the middle of the Strand, and are shifted by numerous small faults. The vein traversing the felsite-porphyry at the western end is also of this type (fig. 5, p. 662), a similarity which suggests a clue to the date of their intrusion. Other irregular tongues and veins are of a more andesitic type and penetrate the felsites, particularly at the western end of the Strand, where they are much decomposed and crushed. The original character of these rocks is obscure.

There are several more or less distinct types of these veins in the

cliffs near Sheep Island, piercing the felsites and other rocks there, but they are only distinguishable under the microscope. Some are trachytic and pale grey, but another type is of a darker greenish tint. Veins with a similar behaviour and mostly of a dark-greyish colour occur between this point and the Black Door, Kilfarrasy, where an exceedingly crushed and altered large intrusive mass, of a pale greenish-grey and with a soft soapy feel, is seen to be intrusive in the felsites. Its true characters are doubtful, but it seems to resemble the keratophyres. A few small veins penetrate the rocks in the cliffs of Kilfarrasy Strand, and one of a trachytic character is noticeable on account of its anticlinal curvature. There are several similar veins of much the same petrological character between this spot and Green Island, and in some cases they enwrap the agglomerate in the felsitic vents. More veins, also piercing the felsites and exhibiting the same pale-grey coloration, occur in Annestown Bay, along Morageeha Strand, where they invade the slates but have not suffered the same crushing; others are noticeable near the Long Rock, on Knockane Strand, and near Dunabrattin. Nearly all of these are of a trachytic type. It is interesting, particularly with regard to their relative age, to find a vein of this character piercing the bostonites at Foilnaneena Cove.

Below the Knockmahon engine-house a pale greenish-grey intrusive vein penetrates the felsites and other rocks, but is affected by the faults. On the eastern side of Ballydouane Bay there is a considerable development of keratophyres, penetrated by some later felsitic veins, but their other relations are not clear. With the exception of a few keratophyric tongues piercing the altered Tramore Limestones in Ballydouane West Bay, but themselves cut by later felsitic intrusives in Killelton Cove, no veins belonging to this group have been observed farther west along the coast-line.

f. Intrusions of Various Types.

Among the felsitic rocks mention has been made of several intrusions of felsite-porphyries, which, though associated in most cases with the former, do not invariably belong to the same period of activity.

There is first the grey felsite-porphyry at the western end of Garrarus Strand, later than the felsites, but earlier than the trachytic or andesitic veins. The grey felsite-porphyry at the Long Rock, near Knockane Strand, Annestown, is not clearly of later date than the felsites there exposed, while that at Foilnaneena Cove is later than the bostonites and is associated with a vent. Below the engine-house at Knockmahon the bluish-grey felsite-porphyry is pierced by some of the felsites, and that on the coast nearer Bunmahon breaks through the augite-porphyrite and other rocks; probably that by Bunmahon Bridge is of the same age. The red felsite-porphyry of Ballydouane West Bay cuts through all the other rocks there, so far as can be seen, except the Old Red Sandstone; and the greyish

felsite-porphyry of Ballyvooney Cove encloses portions of the intrusive felsites which have been injected into the black slates at that spot.

Between Knockmahon and Bunmahon a remarkable purplish or dark-greenish augite-porphyrite is exposed in the series of small coves. It contains in parts numerous small xenoliths, and is associated with a large mass of agglomerate and tuff composed of fragments similar to the xenoliths in the porphyrite. The fine purple slates are interbedded with very fine tuffs of similar materials. The solid rock from which many of these fragments are derived is found in juxtaposition. All these rocks have been pierced first by veins of somewhat similar constitution and by dolerites, subsequently by felsites and felsite-porphyries (see fig. 8, p. 668), and have also suffered mechanical disturbance. Their true place in the bedded series can only be conjectured, no other rocks of similar character being found elsewhere in this district. It should be mentioned that on the Geological Survey Map (Sheet 178) an asterisk indicates that fossils have been found near this spot in the midst of what is coloured as greenstone-ash. 'Felspathic grits and ashy shales' are mentioned by Sir Archibald Geikie[1] as occurring here.

Another rock which bears some resemblance to this augite-porphyrite occurs on the west side of Bunmahon Head, where it penetrates the green tuffs. It is a dark-greenish rock with fine fresh phenocrysts of augite visible to the naked eye. The other occurs below the altered Tramore Limestones, the base of which it penetrates, in a cove on the west side of Ballydouane Bay, but its resemblance is chiefly confined to the presence of large phenocrysts of augite.

In the next place may be mentioned a group of peculiar dark-grey or greenish rocks at Foilnaneena Cove, Tankardstown, resembling some kinds of trachytes and in many respects bostonites (see Types H & I, Felsites, p. 683). These rocks are earlier than the felsite-porphyry and the pale-grey dykes and veins, both of which pierce them; but they are themselves probably intrusive in the purplish and mouse-coloured slates exposed in the face of the cliffs a few yards to the west. At the critical points, however, the whole section is much obscured by landslips and débris from the abandoned workings for copper, the presence of which is abundantly evident.

Rocks of similar character are found on the east side of Bunmahon Head, where some of them appear to be connected with a neck on the foreshore, and others pierce the green Bunmahon Rock (see p. 678) as dykes or veins. The presence of similar rocks of uncertain age has also been detected below Knockmahon and in Cooneenacartan Cove, but nowhere else along the coast, except perhaps in the coves opposite Carrigaghalia near Tramore, where the pale-grey intrusive sheets in the *Dicranograptus*-shales are of a somewhat similar type.

[1] 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 249.

The rock which crosses the head of Stradbally Creek is a diorite of a type not met with elsewhere along the coast. It forms a large irregular intrusive sheet piercing the black slates, and is later than the period when they received their cleavage.

There is a peculiar intrusive rock near Tramore traversing the bedded felsites immediately north of Doneraile Cove. It is lilac-grey to greenish-grey, with small irregular yellow patches, and rings under the hammer like a felsite. From the hand-specimen its true nature cannot be determined, but the microscope (see p. 688) throws some light on its characters. A variety of this rock, forming part of the same mass, shows small, irregularly-oval, yellowish-green spots enclosing a darker centre. This intrusive mass appears to be earlier than the diabase-sheet previously described, but it is pierced by some of the smaller intrusive veins.

The Bunmahon Rock and its associated dark-green tuffs form most of the cliffs on the western side of Bunmahon Bay. It is a dark-green, tough, compact rock, not at all decomposed, but showing small patches of bright greenish-yellow epidote and a granular fracture. The felspars of the groundmass are distinctly visible on a freshly broken surface, embedded in the dark greenish-grey matrix. Various faults and planes of crushing traverse it, and intrusive sheets of a dark-green compact rock of a bostonitic type (p. 683), and some other dark green felsitic dykes or veins pierce it. The cliffs a few yards to the west consist of fine compacted tuffs, and these are pierced by intrusions of a peculiar type of greenish-grey felsitic rock, one dyke of which forms a conspicuous flying buttress. The site of the vent from which the clastic materials were ejected is found on the foreshore, being indicated by an assemblage of fragments, large and small, of the surrounding solid rocks. Coarse green tuffs of this character compose the cliffs and foreshore up to the faulted mass of Old Red Sandstone and on the west side of it.[1] The outpouring of the Bunmahon Rock and tuffs was certainly prior to the veins, dykes, and sheets which penetrate them, and also to the Old Red Sandstone.

III. Petrological Notes.

a. The Felsites.

It has been noticed by several geologists that there is more than one type of felsite, both chemically and microscopically, in this area. Thus Dr. Hatch[2] mentions the analyses given by Haughton[3] and J. Arthur Phillips,[4] and remarks upon their different characters, describing at the same time two other felsites of which he tabulates analyses. One of the latter, called a potash-felsite, was found at a locality 1 mile west of Great Newtown Head, and it is suggested that it represents a devitrified pitchstone. The other

[1] Quart. Journ. Geol. Soc. vol. liii (1897) p. 280.
[2] Geol. Mag. 1889, p. 546. [3] Trans. Roy. Irish Acad. vol. xxiii (1859) p. 615.
[4] Phil. Mag. vol. xxxix (1870) pp. 13–14; Geol. Mag. 1889, p. 288.

analysis is of a boulder of dark-grey banded felsite from the coast near Annestown, and is grouped with the potash-soda felsites. The rock which Haughton analysed was from the neighbourhood of Bunmahon, while Phillips's first analysis is of the Knockmahon quartz-porphyry, and his second is of a flesh-coloured soda-felsite near Annestown. Dr. Hatch compares these Waterford felsites with others from the counties of Wicklow and Wexford,[1] where rocks of the same general age are largely developed.

The analyses of the four felsites by Haughton, Phillips, and Hatch are appended, together with an analysis of the grey felsite from Garrarus made for me by Messrs. H. O. Jones & R. Robinson, of Clare College, in the Cambridge University Laboratory.

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	77·20	80·50	71·0	75·6	80·55
Al_2O_3	6·54	8·33	14·2	12·8	9·87
Fe_2O_3	5·82	3·44	·8	—	2·13
FeO	—	·96	·7	1·9	—
CaO	1·81	1·21	trace	·1	2·21
MgO	·60	trace	1·1	·4	·81
K_2O	3·69	1·89	9·6	5·6	2·43
Na_2O	3·03	2·12	·7	3·0	·42
H_2O	1·12	1·38	1·5	·5	1·06
	99·81	99·83	99·6	99·9	99·48
Specific gravity	—	2·64	2·626	2·606	—

I. 'Pale greenish felstone, stratified,' Bunmahon (Haughton).
II. Flesh-coloured felsite from cliff near Annestown (Phillips).
III. Compact brown felsite, 1 mile west of Great Newtown Head (Hatch).
IV. Compact dark-grey banded felsite, boulder near Annestown (Hatch).
V. Grey felsite intrusive in black slates, Garrarus Strand (see p. 661).

From the foregoing analyses it will be seen that only No. II can be classed as a soda-felsite, all the others being potash-soda felsites (Nos. I & IV) or potash-felsites (Nos. III & V). From microscopical characters it is, however, apparent that soda-felsites (keratophyres) of several types are represented in this area as in Wicklow (see p. 683, Type G, etc.).

Microscopically, the felsites are divisible into several groups according to the characters of their groundmass. This is a convenient method of grouping them, but perhaps not entirely natural, as some of the types of groundmass are due to secondary changes. A complete series of chemical analyses would probably enable us to distinguish the three groups of potash-felsites, potash-soda-felsites, and soda-felsites which Hatch discovered in this petrographical province. The extinction-angles of the majority of the plagioclase-phenocrysts indicate albite.

The first type (Type A) to be mentioned is the microcrys-

[1] Geol. Mag. 1889, p. 70, & Mem. Geol. Surv. Irel. 1888, Explan. Sheets 138 & 139, p. 50.

talline. Generally rocks of this kind, which comprise most of the bedded grey felsites near Great Newtown Head (p. 660), contain large porphyritic felspars, mostly plagioclase, with albite-twinning or microperthitic structure and extinction-angles of 13° to 15°. A few phenocrysts of orthoclase also occur, but none of quartz. The phenocrysts have rounded angles, and are frequently corroded or broken. The associated tuffs from this locality in some cases contain fragments of microlithic felsites and of pumice and large broken quartz-crystals, in addition to pieces of the microcrystalline felsites.

Some of the felsites of this series and with this type of groundmass are practically devoid of phenocrysts, while others contain phenocrysts of quartz, and the porphyritic felspars exhibit mostly very fine albite-twinning with extinction-angles of 6° to 8°. Xenoliths of slate, etc. are common in these felsites, and flow-structure is frequently observable.

In other parts of the area felsites with a microcrystalline groundmass are common: some have only phenocrysts of quartz (Morageeha Strand, p. 666); others contain practically no porphyritic elements (Black Door) or only a very few small ones; and in a dark-green felsite these are replaced by a greenish isotropic material, as are also portions of the groundmass (Bunmahon Bay).

Some felsites have parts of their microcrystalline groundmass granular, or wholly composed of a very fine granular aggregate (Black Door). A groundmass composed principally of grains of quartz and felspar of irregular size, but with parts microcrystalline and with a few plagioclase-phenocrysts, is sometimes found (pink felsite-dyke, Bunmahon Head, p. 669); and near Kilfarrasy Island the banded intrusive felsite has a clear and regular, finely granular, groundmass containing a few large fresh phenocrysts of orthoclase and plagioclase, with extinction-angles of 14° to 18°, and vesicles filled with secondary quartz. A ring of regularly arranged grains of the groundmass is observable round the vesicles and some of the phenocrysts.

Flow-structure is noticeable in many microcrystalline felsites from various parts, particularly in those which have the groundmass also partly cryptocrystalline (Kilfarrasy Strand); and the lines of flow sweep round the xenoliths or phenocrysts, which are mostly of small size, but are in some cases large and consist of quartz and felspar. The banded felsites often show no trace of the banding with crossed nicols.

The microcrystalline type of groundmass passes into the cryptocrystalline (eastern end of Morageeha Strand), for both are frequently associated together in the same rock, and felsites of this composite type may contain no phenocrysts or only a few. Well-developed perlitic structure is frequently met with in rocks of this type (Lady's Cove, Garrarus), and in these examples a few large decomposed orthoclases are the only phenocrysts. Instances of flow-structure have been mentioned above.

The completely cryptocrystalline type (Type B) is common. Frequently there are no phenocrysts present (western

end of Garrarus Strand). Some of the rocks exhibit a few of felspar; in others the phenocrysts are larger and more numerous, and mostly of plagioclase, some with very fine albite-twinning and extinction-angles of 12° to 15°, others with less frequent twinning and larger extinction-angles of 18° to 20° (Garrarus Strand).

Some of the cryptocrystalline felsites without phenocrysts from this locality show flow-structure; others with phenocrysts show this structure; and perlitic structure is found in many (Lady's Cove, Garrarus), the cracks being filled with a pale-greenish material as in the microcrystalline examples. In one case, portions of the cryptocrystalline groundmass are composed of minute microspherulites which give a distinct black cross with crossed nicols.

There is one cryptocrystalline felsite from Lady's Cove, Garrarus, which deserves separate mention because the porphyritic felspar-crystals in it have been converted into a clear coarse granular aggregate which still retains the original outlines of the crystals.

Another felsite, the nodular rock near Bunmahon (p. 669), has its groundmass almost wholly isotropic, and only a few small quartz-crystals occur as phenocrysts. Here may be mentioned a perlitic felsite from Lady's Cove, Garrarus, with likewise a nearly isotropic groundmass, thickly set with small angular grains of clear quartz, and containing also a few large porphyritic felspars with rounded angles.

Some of the felsites with a cryptocrystalline groundmass contain xenoliths of other felsites; especially is this the case with the greenish felsites between Kilfarrasy and Green Island and around Annestown, in which xenoliths are very abundant as well as phenocrysts of felspar (pp. 663–65).

The micropoikilitic type of groundmass (Type C) is occasionally found. Dr. Hatch [1] mentions several examples. In some cases (Lady's Cove, Garrarus, and Sheep Island) this structure only occurs in disconnected patches in a generally microcrystalline groundmass, and the mosaic is fine and blurred. Numerous crystallites, globulites, and margarites, and a few large porphyritic orthoclases and plagioclases with rounded angles occur in these rocks. In another from Garrarus with similar groundmass there are scarcely any phenocrysts. In another case from Kilfarrasy, in addition to felspar-phenocrysts a few large rounded quartz-crystals are seen, round which a fine radial growth has formed; the groundmass is almost wholly micropoikilitic, but parts are pseudospherulitic. Indeed the micropoikilitic patches in the rock previously mentioned frequently show radial structure, and the groundmass of some of these patches appears to consist of closely-packed, irregularly-defined pseudospherulites. The blurred micropoikilitic groundmass of a dyke on Knockane Strand shows traces of similar structure.

Occasionally the groundmass is regularly micropoikilitic without any phenocrysts (Kilfarrasy), or with very few, apparently of orthoclase (Morageeha Strand). A beautiful example of the coarser type with granophyric structure developed in each patch of the

[1] Geol. Mag. 1889, p. 547.

mosaic, and a few large irregular patches of clear quartz-grains, is a felsite from near Garrarus. The mosaic is sometimes blurred (sheet of banded felsite west of Kilfarrasy Island, p. 664).

The clear micropoikilitic groundmass composed of small patches passes often into a granular or coarsely microcrystalline aggregate or mosaic in which the true characters of the micropoikilitic type are absent (Type D). Such are several from Garrarus. In many cases the mosaic is blurred, and phenocrysts may be wholly absent, as in the case of the sheets between Foilnaneena and Knockmahon.

Granophyric as well as microcrystalline and granular structures are found associated with the micropoikilitic occasionally (Type E), as in a rock from the cliffs on the east side of Sheep Island with large porphyritic rounded quartzes and a very few large decomposed orthoclases. The columnar felsite from Kilfarrasy Island (p. 666) has a groundmass of this type, but contains only a few large felspar-phenocrysts.

The dykes cutting across the augite-porphyrite near Knockmahon (p. 668) are of this granular-micropoikilitic type, occasionally with obscure pseudospherulites; and in the columnar felsite of the 'Bishop's Library' granophyric structure is combined, and the groundmass also contains large rounded orthoclases and smaller plagioclases with crowds of crystallites.

A mosaic of small granophyric patches, clear or blurred, forms a special type (Type F) of groundmass, but is connected closely with the micropoikilitic type by transitional varieties. Some of these contain large phenocrysts of felspar showing microperthite. Typical examples of this granophyric mosaic are found in the late intrusive felsite from Newtown Head and other localities (Garrarus, Morageeha, etc.). These have usually phenocrysts of orthoclase, and granular patches of clear secondary quartz. But some are devoid of phenocrysts or contain a few small pseudomorphs of quartz after felspar, or of a greenish substance after felspar with crowds of crystallites (Lady's Cove, Garrarus). Especially beautiful examples of the granophyric mosaic are found in slides containing a few small porphyritic plagioclases (extinction-angles 16° to 18°), as in the horny grey felsites on the west side of Dunabrattin Head, and in the pink felsite on the west side of Sheep Island, which contains as well a few very large imperfect orthoclase- and quartz-phenocrysts.

In other cases the felspar-phenocrysts have themselves been more or less completely replaced by a granophyric mixture similar to that which forms the groundmass, but slightly coarser in texture (as, for example, the red felsite by Sheep Island).

Another type (Type G) of groundmass is characterized by the presence of more or less numerous felspar-microlites or laths. In one example from the east side of Dunabrattin Head (p. 666) the groundmass is micropoikilitic, but crowded with small laths

and microlites of felspar, with a few quartz-grains and some large porphyritic plagioclases which have extinction-angles of 20° to 22°. The groundmass may be partly microcrystalline (nodular felsite, Ballydouane West Bay) or wholly so, or cryptocrystalline (plug of felsite between Knockane and Morageeha Strands, p. 666), or the two kinds may be combined. The felspar-laths may be arranged subparallel in lines of flow (western end of Morageeha Strand), or this structure may be indistinct or absent. By an increase in the number of felspar-laths and a diminution of the crypto- or microcrystalline groundmass, this type is linked to the trachytic and bostonitic.

In the trachytic type (Type H) the groundmass consists principally of closely-packed, short, stout laths of felspar, mostly untwinned, with interspersed, small, clear, micropoikilitic or granophyric patches (Cooneenacartan Cove). The laths are arranged here and there in lines of flow and give almost straight extinction, but there are a few large plagioclase-phenocrysts with extinction-angles of 12° to 16°, and a few grains of quartz. In one rock from this locality the porphyritic felspars have much finer and more frequent albite-twinning and give extinction-angles of 20° to 25°. In others from here and Bunmahon more or less abundant interstitial greenish material occurs, which is isotropic or nearly so with crossed nicols. Needles of apatite are commonly present, and some grains of epidote. A variety from Knockmahon and Bunmahon with long felspar-laths is worthy of notice.

All the examples of the two foregoing types are characterized by more or less abundant patches of micropoikilitic or granophyric structure, but they pass imperceptibly into rocks (Type I) in which this is almost or entirely absent, and which closely resemble bostonites. The greenish interstitial material is much reduced in quantity, and the rock practically consists of small felspar-laths, with occasionally a few grains of magnetite and quartz, and some porphyritic felspars (Ballydouane West Bay, Cooneenacartan, etc.). Flow-structure is generally noticeable among the felspars. In others the felspars are of all sizes, ranging from microlites to large phenocrysts with Carlsbad- and albite-twinning, and set in a pale-greenish matrix. In these no definite flow-structure is observable (Foilnaneena and Bunmahon Bay).

The Wicklow keratophyres[1] resemble some of the rocks of Type G; and it has been noticed that the chemical composition of some keratophyres and bostonites is very similar.[2] The trachytes described by Dr. Hatch[3] from the Lower Carboniferous of Haddingtonshire

[1] Hatch, Geol. Mag. 1889, pp. 70 & 547.
[2] Kemp & Masters, Trans. N. Y. Acad. Sc. vol. xi (1891) p. 13; J. H. Sears, Bull. Mus. Comp. Zool. vol. xvi (1890) p. 167; Rosenbusch, Tscherm. Min. u. Petr. Mitth. vol. xi (1890) p. 144; and J. S. Diller, Bull. Mus. Comp. Zool. vol. vii (1881) p. 165.
[3] Trans. Roy. Soc. Edinb. vol. xxxvii (1892) p. 119.

deserve comparison, and Mr. Harker[1] has remarked that some of these closely resemble some of the rocks called bostonite. It is probable that many of the Waterford felsites with the abundant phenocrysts of plagioclase (albite) are soda-felsites.

b. The Diabases and Dolerites.

All these rocks were classed as 'greenstones' in the Geological-Survey maps and memoirs, but they show considerable diversity in structure and composition. In County Wicklow greenstones and basic sills of probably the same age have been described by Mr. Teall,[2] Dr. Hatch,[3] and A. von Lasaulx.[4] While some of them are diabases others are varieties of diorite, and some of the Waterford rocks may belong to the latter category. Most of the rocks are considerably decomposed.

Some of the Waterford basic sills show true ophitic structure (Tramore Bay, etc.); but in others, though the felspars have crystallized out earlier than the ferromagnesian minerals which mould them, they cannot be described as truly ophitic (Little Island, Great Newtown Head). The augite is usually replaced by some chloritic mineral, frequently of a bright green colour, but in other cases it is nearly or quite fresh. Some of them have portions of the unindividualized groundmass containing small felspar-laths between the felspar-crystals (Newtown Head, Passage); but in other parts of the same rock-mass this may be entirely absent and the structure almost holocrystalline, all the constituents being allotriomorphic, and apparently having crystallized out simultaneously.

Many of these diabases contain quartz (Tramore Bay), and in some cases it appears to be original. Apatite is a common constituent, and ilmenite or leucoxene is always present in skeleton-crystals, large plates, or small grains. The felspars are mostly varieties of labradorite, but are as a rule much decomposed. Some of the so-called diabases might more correctly be ascribed to the diorite family (Garrarus, Tramore), so far as their structure goes, but in no case has hornblende been detected, its place being taken by augite or its decomposition-products. The holocrystalline appearance of these rocks under the microscope, and the absence of ophitic structure and of all interstitial material, suggest that they might be put among the augite-diorites which are so well developed in Wicklow. Some contain quartz.

The dolerites are very few, and call for no special mention. Two from the neighbourhood of Great Newtown Head are of the nature rather of andesitic dolerites. The augite is occasionally found in fairly fresh porphyritic crystals, but is generally intersertal and granular. The felspars are generally much decomposed, and iron-ores are usually abundant.

The appearance in the field of many of the rocks belonging to the

[1] 'Petrology for Students' 1895, p. 150.

[2] 'British Petrography' 1888, pp. 249 & 266.

[3] Mem. Geol. Surv. Irel. 1888, Expl. Sheets 138 & 139, p. 43; Geol. Mag. 1889, p. 261.

[4] Tscherm. Min. u. Petr. Mitth. vol. i (1878) p. 441.

group of the smaller intrusive veins might lead one to attribute them at first to the dolerites or andesitic dolerites; and some are in so decomposed a condition that even sections under the microscope do not prove of much assistance in determining their true character.

c. The Rocks of the Smaller Intrusive Veins.

Several more or less distinct types are recognizable under the microscope in this somewhat mixed assemblage. Most of the rocks are in a highly decomposed condition, and their original characters are hard to distinguish. Many may be ascribed to the andesitic trachytes, but possibly some of these should rather be classed with the keratophyres, as suggested to me by Mr. Henry Seymour, of the Geological Survey of Ireland, who kindly examined a few slides. In macroscopic character these rocks vary from light-grey to dark-green, are opaque in appearance, and have a rough fracture.

A large number of microscope-sections have been examined by me. The predominant constituent is felspar, which occurs in lath-shaped crystals of generally perfect crystalline form, and when sufficiently fresh they indicate by their optical characters that they belong to the albite or oligoclase-andesine group. The ferromagnesian elements are not abundant, and have usually been replaced by chlorite and other secondary products, such as calcite, epidote, etc. Frequently augite seems to have been present, and to have been idiomorphic. Magnetite occurs in grains or rods, but ilmenite or leucoxene is often observable as the predominant iron-ore. Quartz-grains are not uncommon. The groundmass is sometimes abundant, and contains the generation of smaller lath-shaped crystals or microlites of felspar.

In many the trachytic character is more marked (Doneraile Cove, etc.), but in others near Sheep Island the larger felspars are less numerous, while the groundmass is microcrystalline and more abundant, so that these rocks might be classed with the more acid felsites.

In others (Newtown Head, Passage) the groundmass consists of numerous small short felspar-crystals, with comparatively few larger felspars, and occasionally the latter are almost completely absent (Knockmahon). In these last-mentioned examples the ferromagnesian constituents are very rare. There are many examples of this type along the Waterford coast, and some of them show signs of flow by the parallelism of the felspar-microlites (Newtown Head, Passage, and Bunmahon). Some have skeleton felspar-crystals (eastern side of Garrarus Strand).

There are a few of these smaller intrusive veins in which the groundmass is micro- or cryptocrystalline, and no ferromagnesian minerals are apparent. These are rather rhyolitic than trachytic felsites (Sheep Island). A fine microlithic felt occasionally forms the groundmass (Foilnaneena, Garrarus, Kilfarrasy, fig. 6, p. 664), and in some cases these rocks contain small phenocrysts of pyroxenes: they should perhaps be assigned to the andesites. In a curious banded example with flow-structure from Garrarus the lighter

bands of the rock break up with crossed nicols into a blurred mosaic with very few microlites and crystallites, while the darker, more opaque bands are cryptocrystalline or almost isotropic and contain numerous felspar-microlites and small laths arranged in lines of flow. The porphyritic felspars in this rock are replaced by a finely granular aggregate, and there are some large phenocrysts of augite replaced more or less by chlorite and some smaller crystals of enstatite.

The glassy type of groundmass is rare, but is found in small veins near Tramore village. With crossed nicols the groundmass appears cryptocrystalline or nearly isotropic, and there are generally no recognizable felspathic minerals. Sheaf-like or fan-shaped groups of crystallites and scattered grains and rods are abundant.

From the foregoing review of the petrological characters of the rocks of the small intrusive veins, it will have been apparent that several types of rock are present, ranging from keratophyres to trachytes, rhyolites, and andesites, with intermediate varieties. An analysis of one of the trachytic group above mentioned from Newtown Head, Passage, made for me by Messrs. H. O. Jones & R. Robinson in the Cambridge University Laboratory, gave the following results:—

	Per cent.
SiO_2	64·49
Al_2O_3	16·88
Fe_2O_3	6·16
CaO	2·45
MgO	3·10
K_2O	3·89
Na_2O	2·19
MnO, TiO_2	traces
Moisture	·55
	99·71

d. The Felsite-Porphyries.

Quartz-porphyries as well as felspar-porphyries are here included. These rocks are usually pale-grey or blue, but some are pink or reddish. The chemical composition of that below the engine-house at Knockmahon (p. 676) is given by J. Arthur Phillips,[1] for his short description of the rock completely tallies with the characters seen in a hand-specimen:—

	Per cent.
SiO_2	72·33
Al_2O_3	9·02
Fe_2O_3	6·34
FeO	1·06
CaO	1·92
MgO	trace
K_2O	1·46
Na_2O	5·83
H_2O	1·83
	99·79
Specific gravity	2·66

[1] Phil. Mag. vol. xxxix (1870) pp. 12–13; Geol. Mag. 1889, p. 288.

The predominance of the soda-felspars is suggested by the above analysis, and the microscopic examination of the rock-sections confirms this view. The groundmass is microcrystalline, and is crowded with large perfect phenocrysts of albite and with large corroded crystals of quartz. Parts of the groundmass form a fine granular mosaic. Some connexion between these soda-felspar porphyries and the soda-granites in Wicklow has been suggested.

In others quartz-phenocrysts are less abundant, and the porphyritic felspars are of various sizes, show albite-, pericline-, and Carlsbad-twinning, but give an extinction-angle of only 10°. A few small flakes and phenocrysts of greenish mica are also visible, and the groundmass is granular to micropoikilitic (Bunmahon Bridge). In other cases there are numerous felspar-microlites in the groundmass, which is micropoikilitic (east of Knockmahon). In another the groundmass is microcrystalline, the corroded quartz-phenocrysts are large and more numerous than the felspars, which give extinction-angles of 10°, and the brownish-green mica is abundant and of earlier formation than the quartz (Ballyvooney Cove). The groundmass in the example on Garrarus Strand (fig. 5, p. 662) is cryptocrystalline, there are no quartz-phenocrysts, but the porphyritic felspars are large, numerous, and extinguish at 15° to 20°. The pink felsite-porphyry near Ballydouane has a similar groundmass, but it contains large quartz-phenocrysts and also large felspars with the peculiar structure of anorthoclase.

In a variety of the felsite-porphyry of the Long Rock, Knockane Strand, the groundmass is composed of pseudospherulites of various sizes scattered among large clear micropoikilitic patches. In another near Knockmahon (fig. 8, p. 668) the groundmass is micropoikilitic, but contains numerous short laths of felspar. There are large phenocrysts of plagioclase-felspar, but none of quartz.

e. The Augite-Porphyrites.

The augite-porphyrite of Knockmahon (fig. 8, p. 668) is macroscopically a dark-purplish or greenish rock, often having an irregularly blotched appearance. The porphyritic crystals of augite are conspicuous on a freshly-broken surface. There is some variation in the composition of the rock and number of phenocrysts, but its general characters are as follows:—The groundmass is cryptocrystalline, crowded with small laths of felspar (but not truly hyalopilitic) showing frequently lines of flow by a rough parallelism; abundant grains of magnetite also occur. The phenocrysts of augite are large, perfect, and fairly numerous, but are partly or entirely pseudomorphed by chlorite. The felspar-phenocrysts are smaller, comparatively rare, and much decomposed.

A greenish porphyrite which occurs in the form of veins piercing this augite-porphyrite at Knockmahon, and shows columnar structure in parts, has an abundant pale-brownish cryptocrystalline groundmass without very numerous small felspar-laths, but with a large number of small phenocrysts of felspar scattered through it and a very few pseudomorphs of chlorite after augite.

Small patches of chlorite, grains and rods of magnetite, and secondary quartz occur in the groundmass.

One of the only other two rocks that can be termed augite-porphyrites occurs on the west side of Bunmahon Head (p. 677). It is of a greenish colour, and looks like a dolerite in the hand-specimen. The groundmass consists of a mass of closely-packed small felspar-laths arranged in subparallel lines of flow with intersertal grains of fresh augite, a few felspar-phenocrysts of medium size, and a few large perfect crystals of fresh augite. There is very little interstitial material, and not much magnetite.

The second example (Ballydouane Bay, p. 677) has an abundant cryptocrystalline or nearly isotropic groundmass, with numerous small, decomposed, isolated felspar-laths, small pseudomorphs of chlorite after augite, a few large porphyritic felspar-crystals, and some large irregular phenocrysts of pale augite partly replaced by chlorite.

Another porphyrite with a glassy almost isotropic groundmass, filled with small scattered microlites of felspar and small irregular patches of chlorite and a few xenoliths, contains also numerous crystals and grains of felspar mostly untwinned and of small size, but no other phenocrysts. This rock is of rather an uncommon type, and occurs in association with the augite-porphyrite of Knockmahon. A somewhat similar rock from the same locality has its groundmass composed of a pale-greenish almost isotropic material, filled with felspar-crystals of various sizes, but mostly elongated large laths. A little iron-ore in large skeleton-crystals is also present.

f. Miscellaneous Types.

The peculiar pale-greenish or violet-grey rock with brownish-yellow blotches which occurs near Doneraile Cove (p. 678) has somewhat the appearance of a felsite in the field, but suggests a keratophyre under the microscope. There is fairly abundant brownish interstitial material between the large laths of felspar which make up the bulk of the rock. This interstitial material contains minute grains of magnetite or ilmenite, and irregular patches of pale chlorite. The felspars are entirely replaced by a finely granular or saussuritic aggregate, and secondary minerals, especially calcite, are abundant. A few large crystals of ilmenite, often changed into leucoxene, are noticeable. The brownish patches enclose and enwrap the felspars, and are distinct from the groundmass; though they hardly seem definite enough to represent ophitic plates of any mineral.

The 'greenstone' intruded into the slates in Stradbally Creek (p. 678) is of a peculiar type, for it consists almost entirely of large idiomorphic or nearly idiomorphic felspars with extinction-angles of 12° to 15°. There is no original interstitial material, but the spaces between the felspars are filled up by a pale-greenish chloritic mineral, perhaps representing ophitic augite. There are also a few decomposed skeleton-crystals of ilmenite and grains of epidote. Probably it is a diorite.

The rock forming the headland west of Stradbally (p. 670), and termed a felsite in the Geological Survey Memoir, is of somewhat doubtful nature. Under the microscope, it is seen to consist mainly of felspar-laths, mostly untwinned, with larger squarer felspar-crystals interspersed having extinction-angles of 15° to 16°. Irregular small patches of a pale chloritic mineral frequently mould the felspars. A few large micropoikilitic patches of quartz are noticeable, and grains of brightly-polarizing epidote are plentiful.

A rock in Bunmahon Bay, consisting of large numbers of plagioclase-crystals of various sizes embedded in a micro- to cryptocrystalline groundmass containing felspar-microlites and pale-greenish grains, and also porphyritic pseudomorphs of the same pale-greenish isotropic material after some pyroxene (?), is a peculiar type. The felspars show irregular albite-twinning and low extinction-angles of 6° to 8°. Magnetite-grains and small crystals are also present. Probably the rock should be referred to the porphyrites.

The dark-greenish compact rocks penetrating the augite-porphyrite at Knockmahon and in the adjoining coves are of a peculiar type. A pale-greenish uniform groundmass, closely set with small felspar-laths, is almost isotropic with crossed nicols, and magnetite and secondary quartz are present. Similar rocks, but with occasional phenocrysts of plagioclase, form conspicuous flows in Cooneenacartan Cove, and in these much of the groundmass is found to be of fibrous hornblende giving extinction-angles of about 20°.

The rock (p. 678) forming the greater part of the western side of Bunmahon Bay is of a peculiar and somewhat enigmatical character. It is greenish in a hand-specimen, with the porphyritic felspars distinctly visible. Under the microscope it is seen to be composed of a brownish matrix, isotropic to cryptocrystalline under crossed nicols, and filled with numerous short felspar-crystals, mostly rectangular or square in section, showing albite-, Carlsbad-, and pericline-twinning or none at all, and many of them have rounded angles. The extinction-angles are mostly 10° to 12°, but some are 18° to 20°. In addition there are large irregular isolated patches of pale-green chlorite, but some are of regular crystalline shape and may be pseudomorphous after some pyroxene. Epidote is frequently abundant. The iron-ore is scanty, and is represented by minute grains. Patches of the groundmass are devoid of phenocrysts. The composition of this rock, according to an analysis made for me in the Cambridge University Laboratory, is as follows:—

	Per cent.
SiO_2	59·46
Al_2O_3	18·17
Fe_2O_3	6·52
CaO	1·95
MgO	6·85
K_2O	5·31
Na_2O	·59
Moisture	·62
	99·47

IV. The Age of the Rocks.

In the Geological Survey Memoirs all these igneous rocks, with a few trifling exceptions, are attributed to the Lower Silurian, as are the sedimentary and fossiliferous beds which they pierce. It seems to have been assumed that the great majority were contemporaneous lavas and tuffs, but the evidence now brought forward shows that this generalization is incorrect. Sir Archibald Geikie[1] recently suggested that they belonged to various periods, and were mostly intrusive. The diabase-sheets and elvans have always been recognized as intrusive, and therefore of later date than the rest.

It is possible now to assign a more definite date to many of the intrusive rocks. It is obvious that most are post-Ordovician, though of some this cannot be positively asserted (see p. 660). From the following considerations it is indicated that they are also all pre-Carboniferous. Firstly, the Old Red Sandstone, wherever its relations to them are exposed to view, is seen to rest unconformably upon them, and its basal breccias contain fragments of them.

Secondly, the Old Red Sandstone of Waterford does not contain any contemporaneous interbedded igneous rocks, and shows no sign of having been deposited during a period of vulcanicity. It should, however, be remembered that the Old Red Sandstone of Waterford is attributed to the upper part of that formation, while the Lower Old Red Sandstone is entirely absent and was probably never deposited over this area. On the west, however, where the Lower beds are present, felsites and ashes are interbedded among the latter,[2] and it might be contended that some, at any rate, of the Waterford felsites are of this age. Waterford was at this time a land-area, judging from the coarse littoral deposits at the base of the Upper Old Red Sandstone and the evidence for the subsequent gradual eastward spread of the waters due to submergence. There is nevertheless no direct proof that any volcanic outbursts took place on land or over the Waterford district in Lower Old Red times.

Thirdly, since no felsitic or other igneous rocks pierce the remnants of the Old Red Sandstone in the county, except two or three so-called 'greenstone'-intrusions on the Reeks of Glenpatrick (marked on the Geological Survey Map, Sheet 167, but which I have not had the opportunity of examining), the natural inference is that all the igneous rocks were of earlier date. Of course, this cannot be asserted positively, because so little of the original covering of Old Red Sandstone is preserved, but the main mass as well as the detached outliers along the coast furnish no contradictory evidence.

Farther to the west and north-west of County Waterford there are well-known instances of Upper Old-Red-Sandstone and Carboniferous vulcanicity around Limerick and Bantry Bay[3]; but there is

[1] 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 247, etc.
[2] *Ibid.* p. 346, and references there.
[3] *Ibid.* vol. i, p. 348, & vol. ii, pp. 41, 49.

no direct proof that any of the Waterford igneous rocks belong to so late a period.

It is possible that those igneous rocks which show no signs of having shared in the first post-Ordovician folding are of Silurian or Lower Old-Red-Sandstone date. Only certain of the felsites and tuffs seem to have been involved with the Ordovician sedimentary beds in the plication which gave them their dominant strike in the South-east of Ireland (p. 660). The presence of cleaved fragments of the Ordovician slates in many of the volcanic tuffs and agglomerates; the inclusion of angular chips of the surrounding felsites, etc. in some of the necks; and the manner in which many of the intrusive rocks pierce through the tilted and folded sedimentary beds, show that the consolidation, folding, and cleavage of the latter had been effected before these volcanic outbursts. This folding of the Ordovician beds took place presumably in Silurian times, but how long it lasted is not known. If it was concluded before the end of the Silurian period, some of the above-described igneous rocks may be of Silurian age. The distance of the nearest undoubted exhibition of Silurian vulcanicity does not seem to be a serious difficulty.

The great denudation, of these folded rocks and, so far as we know, of all the igneous rocks also in County Waterford, took place before the deposition of the Old Red Sandstone; and although Sir Archibald Geikie[1] has expressed the opinion that some of the igneous rocks may be of Old-Red-Sandstone age, the evidence along the coast does not favour this view.

From the foregoing considerations it is evident that the time during which the intrusion and effusion of unbedded igneous materials took place in County Waterford is limited on one side by the first post-Ordovician folding, and on the other by the pre-Upper Old-Red-Sandstone denudation. This denudation probably accompanied, and was a result of, the submergence of the area beneath the waters of the Upper Old-Red-Sandstone lake or sea.

Having now defined as far as possible the period of vulcanicity, it is necessary to attempt to determine the succession of events during that period.

In the first place, we may remind ourselves that there was the outpouring of lavas and tuffs during the Ordovician Period, and these were interbedded with the fossiliferous rocks described on a former occasion.[2] Then come the grey felsites and ashes near Great Newtown Head, described in the present paper as overlying these rocks and showing frequently the same general dip and strike. These appear to belong to a period prior to the first post-Ordovician plication, which threw the beds into a series of folds with their axes running north-east and south-west.

Next occurred the outburst of green and pink felsites and tuffs and coarse agglomerates, developed from Great Newtown Head

[1] *Op. cit.* vol. i, p. 251.

[2] Quart. Journn. Geol. Soc. vol. lv (1899) pp. 718–71.

to Garrarus. Probably to this same outburst belong the xenolithic felsites and greenish tuffs exposed between Kilfarrasy and Annestown. It is somewhat doubtful whether these were poured out before the folding of the Ordovician beds, as the mutual relations of the rocks are not very clear, but the felsites and tuffs frequently show stratification and folding, and their strike when traced inland agrees with that of the previous series; so that the available evidence points to their formation prior to the post-Ordovician folding.

Some of the irregular masses of felsite-porphyry appear to have been intruded prior to the injection of the smaller intrusive veins which pierce them and the above-mentioned rocks, but were formed subsequent to the folding.

The small veins, which are of several petrological types and intermediate composition, mark the next stage of igneous activity, but show slight differences of age among themselves.

Next comes the intrusion of the basic sills, diabases, etc., and this was accompanied by the formation of a few doleritic dykes and veins.

Subsequently the igneous intrusions again assumed an acid character, and the felsitic masses of Newtown Head, Passage; of the centre of Garrarus Strand, and of Knockmahon were extruded. Probably at this time too were formed the isolated necks, filled with brecciated fragments of the earlier rocks, which have been described.

The formation of the felspar-porphyry dykes may now have taken place, but perhaps they are of still later age. Some of them may be connected with the intrusion of the Wicklow granites. The numerous isolated felsitic sheets and veins which pierce the folded rocks, especially west of Kilfarrasy, probably belong to this late period, but their relations to the other igneous rocks, except where some of the latter are exposed with them, is generally doubtful; and the most that can be asserted is that they are later than the folding.

The relative age of some of the peculiar types of intrusive rocks has been previously indicated, but in other cases there is no means available by which we can determine it.

V. Conclusion.

By the aid of the facts recorded in the foregoing pages, it has been shown that there are two main periods of volcanic activity exhibited in this area: the first, Ordovician; the second, post-Ordovician, but pre-Upper Old Red Sandstone. Next, that the second period is characterized by a succession of several distinct types of igneous rocks; while the first period is marked solely by outpourings of a felsitic nature.

Discussion.

Sir Archibald Geikie stated that he had examined this interesting region several years ago, and had given some account of its igneous rocks in his Presidential Address to the Geological

Society in 1891. But more recent observation had led him to modify the opinions there expressed. The ground is now under revision by Mr. J. R. Kilroe, of the Irish branch of the Geological Survey, with whom the speaker had the advantage of revisiting a number of the sections last summer. Mr. Kilroe's work showed that the masses of so-called 'agglomerate' along the coast were not really such, but in every case which he had examined were intrusive felsites or other eruptive material, crowded with an almost incredible number of fragments of black shale and various igneous rocks. The matrix was not fragmental, but consisted of lava-form material, sometimes showing good flow-structure. Sir Archibald had been unable to detect any true bedded lavas in any part of the coast-section which he had re-examined, nor could either Mr. Kilroe or himself find any satisfactory evidence that the tuffs, here and there visible, were connected with the Lower Silurian strata. So far as they could see, the eruptive rocks were all intrusive, and belonged (as the Author had said, and as the speaker had formerly suggested) to some period intermediate between the Bala Group and the Upper Old Red Sandstone. They might not improbably be referable to that great epoch of igneous activity which witnessed the intrusion of so much granite in Scotland and Ireland, and in which the copious volcanic discharges took place which gave forth the materials that now form the Pentland, Ochil, and Sidlaw Hills, the heights of Lorne, and various intercalated lavas and tuffs in the Lower Old Red Sandstone of the north and south-west of Ireland. He thought it quite possible that the tuffs of the Waterford coast really belonged to the same period of volcanic activity; but this was a question on which he hoped that Mr. Kilroe's further field-work would throw light. He was glad that the Author had taken up the study of the petrography of the igneous rocks of this region, and had produced a paper which would much assist the labours of students of this singularly interesting but very complicated piece of geological structure.

The President and Prof. Sollas also spoke.

The Author, in reply, said that the abundance of xenolithic felsites and the comparative rarity of true fragmental rocks had been especially noted by him. The foreign fragments in these felsites measured in some cases a yard or more in length, and were often extremely numerous. As to the presence of true bedding in the series of felsitic rocks, he admitted that it was in many instances hard to detect, but in a few cases it seemed sufficiently distinct. The intrusive and unbedded felsites were, however, much more developed than the bedded felsites. True agglomerates were present in the later necks. The date of some of the intrusions probably coincided with that of the granitic masses in the East of Ireland.

36. *On* Radiolaria *from the* Upper Chalk *at* Coulsdon (Surrey).

By W. Murton Holmes, Esq. (Communicated by W. Whitaker, Esq., B.A., F.R.S., F.G.S. Read June 20th, 1900.)

[Plates XXXVII & XXXVIII.]

The occurrence of radiolaria in the Chalk of this country is sufficiently rare to call for some notice, and the present paper has been written at the suggestion of Mr. William Hill, F.G.S., who saw some of my specimens. As was suggested by Messrs. Hill & Jukes-Browne in their paper on Chalk radiolaria,[1] one would have expected the physical conditions of the Upper Cretaceous period to have been more favourable to the existence of such organisms than those of the Lower Cretaceous or of Jurassic times, in the rocks of which periods radiolaria are not uncommon on the Continent.

One reason may be that, as in recent deep-sea dredgings, we find the ooze in some instances to contain radiolaria in considerable numbers, while in others they are either entirely absent or very scarce; so it is possible that in certain tracts of the Chalk there were no radiolaria present when that was deposited. Again, the ready solubility of radiolarian tests, more especially when in contact with carbonate of lime, will account for the disappearance of large numbers.

Dr. Cayeux[2] has given a summary of the papers which been have published on Cretaceous radiolaria.

Prof. W. J. Sollas found some in the Cambridge Greensand in 1873. These, however, were not described. Geheimrath K. von Zittel found in 1876, in the Upper Senonian of Northern Germany, six species of radiolaria belonging to four known genera. Signor Pantanelli in 1880 noted the presence of one species in the Cretaceous of Tuscany. The late Dr. Wallich, in 1883, recorded the presence of four genera (*Astromma*, *Haliomma*, both discoidal and spherical, and *Podocyrtis*) in the cavities of hollow flints from some Surrey gravel-pits. The exact horizon of these could not be determined. Dr. Rüst has figured only two species from the Upper Chalk of England, *Dictyomitra anglica* and *Dictyospiris chlamydea* (quoted by Messrs. Hill & Jukes-Browne). Prof. Fritsch mentions, in his studies on Bohemia (1893), eleven species, belonging to nine genera, in the marly beds of Priesen (Lower Senonian). Dr. Deecke discovered, in 1894, radiolaria in Chalk-flints at Rügen.

Messrs. Hill & Jukes-Browne have observed many forms in the Melbourne Rock, 1895 (*op. cit.*). From the smectite of Battice, near Herve, Belgium, in the horizon of *Belemnitella quadrata*, Dr. Cayeux has described (*op. cit.*) radiolaria belonging to twenty-seven genera. He notices the great predominance of the order Discoidea, and especially of the family of Porodiscidæ.

[1] Quart. Journ. Geol. Soc. vol. li (1895) p. 600.
[2] 'Étude micrographique des Terrains sédimentaires' 1897, p. 185.

In addition to these, Dr. Rüst also described, in 1892,[1] sixteen species occurring in the shales of the Pierre Formation of North-western Manitoba, belonging to the Upper Cretaceous; of these, thirteen were new species.

During the discussion which followed the reading of Messrs. Hill & Jukes-Browne's paper, Prof. T. Rupert Jones referred to the discovery of *Polycistina* in the Chalk in 1883, which was published in Trans. Herts Nat. Hist. Soc. vol. iii (1885) p. 152.

The radiolaria described in the following pages were contained in the cavities of two small flints which were thrown out of the new railway-cutting between Coulsdon Station and the new Merstham Tunnel on the London, Brighton, & South Coast Railway. The exact horizon from which they were derived is difficult to determine, but from the presence on the same heap of numbers of *Holaster planus, Micraster Leskei*, and *Terebratula carnea*, it may fairly be concluded that they came from the *Holaster-planus* zone. The material from the cutting was removed by means of a tramway, and deposited in enormous heaps by the side of the railway. The hollow flints are fairly numerous: in many instances they have a solid cylindrical core and are filled with a mealy substance, which is contained in the cavity between the central core and the outer coating. Caleb Evans[2] notes the occurrence of similar flints in the Lower Kenley Beds. The mealy material inside, after being treated with diluted hydrochloric acid, yielded, besides the radiolaria, large numbers of the silicified casts of foraminifera in good preservation, together with sponge-spicules belonging to the Monactinellidæ, Tetractinellidæ, Lithistidæ, and Hexactinellidæ. Among the smaller spicules may be noted the occurrence of a large inequianchorate of an *Esperia*, ·15 mm. in length. This mixture of organisms is such as may often be found in recent deep-sea soundings.

Although the external forms of the radiolaria from Coulsdon are in most cases easily recognizable, the surface is very much altered by corrosion, and their specific characters are in consequence exceedingly difficult of determination.[3] So much is this the case, that I have been obliged to content myself with the generic name alone in most instances. This is especially true with regard to the Discoidea: their internal structure cannot be discerned from an external view, and the surface-markings on the fossils are frequently due to secondary action. Again, the globate spicules of species of *Geodia* so much resemble in outward appearance many of the Sphæroidea and Prunoidea, especially the forms of *Cenosphæra*, *Conosphæra*, and *Cenellipsis*, that it will be more satisfactory not to attempt their enumeration. The smaller forms of the Cyrtoidea have been also omitted.

[1] Geol. Surv. Canad. 'Contrib. Canad. Micro-Palæont.' pt. iv.

[2] 'On some Sections of Chalk between Croydon & Oxtead' Proc. Geol. Assoc. Suppl. to vol. i (1870) p. 15.

[3] The secondary markings due to corrosion are especially noticeable on some of the sponge-spicules, which exhibit a regular series of pittings.

That radiolaria existed in considerable numbers in the Cretaceous seas is proved by the fact that in the small quantity of material examined forty-one species, belonging to twenty genera, have been recognized.

As in the case of the smectite of Belgium, the Discoidea appear to predominate. Next in numerical order must be mentioned the species of *Dictyomitra.*

My thanks are especially due to Dr. G. J. Hinde, F.R.S., who has very kindly examined the specimens, besides helping me with advice and furnishing me with literature on the subject. His experience in examining fossil radiolaria makes such help invaluable.

Class RADIOLARIA, Müller.

Sub-class SPUMELLARIA, Ehrenberg.

Order **SPHÆROIDEA**, Hæckel.

Genus *Cenosphæra*, Ehrenberg.

The test is a simple latticed sphere without radial spines.

Cenosphæra sp. (Pl. XXXVII, fig. 1.)

Test small. Surface rough, with short spines between the pores, which are circular or subangular. Diameter of test =·1 mm. This corresponds in size with *C. scitula*, Hinde, described and figured in Quart. Journ. Geol. Soc. vol. lv (1899) p. 43 & pl. viii, fig. 2, and with *C. minuta* (Pantanelli), 'Palæontographica' vol. xxxiv (1888) p. 190.

Cenosphæra gregaria, Rüst. (Pl. XXXVII, fig. 2.)

Test smooth. Pores uncertain. Diameter =·19 mm. Thickness of test =·15 mm.

Genus *Stylosphæra*, Ehrenberg.

The test consists of two concentric latticed spheres, with two radial spines.

Stylosphæra sp. (Pl. XXXVII, fig. 3.)

This specimen is much corroded, and the spines are imperfect. Diameter of test =·10 mm. Only faint indications of a medullary shell.

Genus *Trilonche*, Hinde.

The test consists of two concentric latticed spheres, with three radial spines at equal or unequal distances apart. Secondary surface-spines are also present sometimes.

Trilonche sp. (Pl. XXXVII, fig. 4.)

Diameter of cortical test = ·13 mm. Thickness of wall = about ·02 mm. The surface of this specimen is crusted over, and the medullary sphere is very obscure: this is about ·06 mm. in diameter. Spines small, prismatic.

Genus *Acanthosphæra*, Ehrenberg.

The test is a simple latticed sphere, with eight or more radial spines of the same kind.

Acanthosphæra sp. *α*. (Pl. XXXVII, fig. 5.)

Test with large hexagonal pores. Diameter of test = ·155 mm. Spines imperfect, prismatic.

Acanthosphæra sp. *β*. (Pl. XXXVII, fig. 6.)

Small test, with large hexagonal pores. Diameter = ·115 mm. Spines imperfect.

Order **PRUNOIDEA**, Hæckel.

Genus *Lithapium*, Hæckel.

The test is a simple latticed shell, with a radial spine at one pole.

Lithapium sp. (Pl. XXXVII, fig. 7.)

Test small: long diameter = ·105 mm.; transverse diameter = ·09 mm. Radial spine reduced to a stump. Pores uncertain. Surface-markings probably due to corrosion.

Order **DISCOIDEA**, Hæckel.

Genus *Theodiscus*, Hæckel.

Test a simple lenticular latticed shell, with three radial spines extending from the margin, at equal or unequal distances apart.

Theodiscus sp. (Pl. XXXVII, fig. 9.)

Test a circular flattened disc. Diameter = ·225 mm. Spines prismatic and apparently serrated; one missing. Length = ·08 mm. Markings secondary.

Genus *Spongotripus*, Hæckel.

Test discoidal, of porous, reticulate, or spongy framework, with three solid radial spines on the margin.

Spongotripus pauper (?) Rüst. (Pl. XXXVII, fig. 10.)

Test triangular in outline, with slightly concave sides. Surface rough and obscure. Length of test without spines = ·23 mm.; breadth = ·175 mm. Length of spines (not quite perfect) = ·15 mm.

This is probably identical with *Sp. pauper*, Rüst, figured in 'Palæontographica' vol. xxxiv (1888) pl. xxvi, fig. 3.

Spongotripus sp. (Pl. XXXVII, fig. 11.)

Test small, triangular, with concave sides. Spines apparently short.

Genus *Trochodiscus*, Hæckel.

The test is a simple latticed disc, with ten or more marginal or radial spines.

Trochodiscus sp. (Pl. XXXVII, fig. 12.)

Test biconvex, with stumps of spines only remaining. Surface rough; markings secondary. Diameter =·20 mm.

Genus Uncertain.

(Pl. XXXVII, fig. 14.) Test circular or slightly oval, with prominent central elevation. Surface rough; markings secondary. Long diameter =·28 mm.; short diameter =·25 mm.

(Pl. XXXVII, fig. 13.) Test oval, with prominent central elevation. Long diameter =·21 mm.; transverse diameter =·15 mm.

(Pl. XXXVII, fig. 15.) Test lenticular. Meshwork secondary. Diameter =·23 mm.

Genus *Coccodiscus*, Hæckel.

Discoidea with an extracapsular phacoid shell (or lenticular latticed shell), connected by radial beams with an intracapsular, simple or double, concentric medullary shell, and surrounded by one or more concentric chambered equatorial girdles on the margin.

Coccodiscus sp. (Pl. XXXVII, fig. 17.)

Marginal disc of spongy meshwork. Diameter =·275 mm. Diameter of central disc =·13 mm.

Similar forms are met with in the Barbados radiolarian earths.

Genus *Trigonocyclia*, Hæckel.

Test discoidal, with lenticular latticed cortical shell, simple medullary shell, and three solid radial spines on the margin of the disc.

Trigonocyclia sp. α. (Pl. XXXVII, fig. 20.)

Test biconvex. Markings secondary. Spines imperfect. Diameter =·25 mm. Medullary shell not seen.

Trigonocyclia sp. β. (Pl. XXXVII, fig. 24.)

Test somewhat triangular in outline, biconvex. Surface very rough. Markings secondary. Greatest length =·21 mm.; length of spine =·05 mm. Medullary shell not seen.

Genus *Rhopalastrum*, Hæckel.

Test bilateral, with three chambered arms and a central chamber, which, however, in the fossil forms is not always recognizable.

Rhopalastrum sp. α. (Pl. XXXVII, fig. 26.)

Arms short, gradually increasing in size towards the distal ends, which are obtusely triangular. Length of arms, measuring from the centre of the test $= \cdot 125$ mm. Breadth at the narrowest part $= \cdot 05$ mm. Greatest breadth $= \cdot 07$ mm.

Rhopalastrum sp. β. (Pl. XXXVII, fig. 19.)

Arms increasing rapidly towards their distal ends, which are truncate. Length of arms, measuring from the centre of the test $= \cdot 21$ mm. Breadth at base $= \cdot 05$ mm. Greatest breadth $= \cdot 125$ mm.

Rhopalastrum sp. γ. (Pl. XXXVII, fig. 23.)

Arms somewhat arched; two terminate in club-shaped prominences, while the third terminates in an obtuse angle. Length of arms from the centre of the test $= \cdot 32$ mm. Breadth at base $= \cdot 055$ mm. Greatest breadth $= \cdot 10$ mm.

Rhopalastrum sp. δ. (Pl. XXXVII, fig. 18.)

Arms similar to those in the foregoing species, apparently proceeding from a central disc. Length of arms $= \cdot 14$ mm.
This is probably a young form.

Genus *Trigonactura*, Hæckel.

Coccodiscidæ having three chambered arms on the margin of the circular or triangular disc, without a connecting patagium, and furnished with spines.

Trigonactura armata, sp. nov. (Pl. XXXVII, fig. 22.)

Length of arms measured from the centre, not including the spines $= \cdot 15$ mm. Breadth at base $= \cdot 075$ mm. Greatest breadth $= \cdot 09$ mm. Length of spines $= \cdot 11$ mm. In a smaller specimen of the same species the central chamber can be distinguished, where the outer part of the shell had been corroded.

Genus *Hagiastrum*, Hæckel.

The test consists of four chambered arms extending from a common centre.

Hagiastrum sp. (Pl. XXXVII, fig. 27.)

Arms arranged at right angles one to the other. Greatest length of entire test $= \cdot 215$ mm. Breadth of two opposite arms $= \cdot 06$ mm.; the other two are somewhat narrower, measuring $\cdot 05$ mm.
There are indications of terminal spines.

Genus *Stauralastrum*, Hæckel.

Porodiscidæ having four simple undivided chambered arms, without a patagium; quadrangular, forming a regular cross, with four equal arms placed at right angles, each terminated by a spine.

Stauralastrum venustum, sp. nov. (Pl. XXXVIII, fig. 1.)

Arms slightly increasing towards the distal end, then tapering to a prismatic spine. Pores obliterated. Length of arms, including spines =·22 mm. Breadth at base =·04 mm. Greatest breadth =·055 mm.

This species is of the same character, but more robust than *St. gracile*, Rüst (siliceous limestone of Cittiglio), 'Palæontographica' vol. xlv (1898) p. 29 & pl. ix, fig 9.

Stauralastrum sp. (Pl. XXXVIII, fig. 2.)

Test elevated in the centre. Arms conical, one only terminated by a spine. Length of arms from centre =·17 mm. Breadth at base =·10 mm. Length of spine =·04 mm.

This species resembles in general outline *Astractura tetraxiphus*, Rüst, 'Palæontographica' vol. xlv (1898) pl. vii, fig. 3, but is without the central disc.

Genus Uncertain.

(Pl. XXXVII, fig. 8.) The nature of this is uncertain: it probably belongs to the genus *Cyphinus*. Surface-markings secondary.

Sub-class NASSELLARIA, Ehrenberg.

Order **CYRTOIDEA**, Hæckel.

Sub-order Monocyrtida, Hæckel.

Genus *Cyrtocalpis*, Hæckel.

The latticed tests are pitcher-, bell-, or egg-shaped, without spines or horn.

Cyrtocalpis cf. *compacta*, Hæckel. (Pl. XXXVII, fig. 16.)

Test skittle-shaped. The pores appear to be secondary. Length =·22 mm. Greatest breadth =·08 mm. Breadth at base =·035 mm.

The recent *C. compacta* is very similar in outline, but is not so large.[1]

Cyrtocalpis, sp. (Pl. XXXVII, fig. 25.)

Test very rough. Height =·14 mm. Greatest breadth =·08 mm. Breadth at base =·05 mm.

[1] Hæckel, *Challenger* Report on the Radiolaria, vol. xviii, pt. ii (1887) p. 1187 & pl. lii, figs. 7–8.

Sub-order Dicyrtida, Hæckel.

Genus *Dicolocapsa*, Hæckel.

The test consists of two segments; the basal segment is oval or globular, and the aperture covered by a latticed plate. The first segment is without a pointed horn on the summit.

Dicolocapsa sp. (Pl. XXXVII, fig. 28.)

Basal segment globular, with polygonal pores. Diameter =·11 mm. Height of first segment =·03 mm.

Sub-order Stichocyrtida, Hæckel.

The latticed test consists of four or more members, with three or more transverse constrictions.

Genus *Lithocampe*, Hæckel.

The conical, oval, or fusiform latticed test has the apertures contracted, and is without a horn-shaped process on the summit.

Lithocampe sp. (Pl. XXXVII, fig. 21.)

Height of test with four segments =·10 mm. Breadth of basal segment =·08 mm. First segment smooth. No pores shown.

Genus *Dictyomitra*, Zittel.

The latticed test is conical or cylindrical, without horn, and with an open basal aperture. The constrictions are horizontal.

Dictyomitra multicostata, Zittel. (Pl. XXXVIII, fig. 3.)

Test slender, conical, with prominent longitudinal ribs, and from eight to ten deep constrictions. Length and breadth of the joints gradually increasing, the eighth joint being twice as long and broad as the fourth joint. Pores regular, circular, one series in each longitudinal furrow; three to four pores in each joint.

In this specimen, which shows seven joints only, there appears to be a double row of pores between each vertical line. Height =·255 mm. Greatest breadth =·10 mm. Breadth at base =·09 mm.

Cretaceous rocks of Brunswick (Zittel). Cretaceous rocks of Pierre Formation of North-western Manitoba (Rüst). Figured by Zittel in the Zeitschrift d. Deutsch. Geol. Gesellsch. vol. xxviii (1876) pl. ii, figs. 2–4.

Dictyomitra tiara, sp. nov. (Pl. XXXVIII, fig. 4.)

The test is large, with nine deep constrictions. The first segment is dome-shaped. The remaining segments have prominent longitudinal ribs. They are inflated, of uniform height, but gradually increase in breadth towards the base. There are indications of pores in the constrictions. Total height of test =·41 mm. Height of segments =·045 mm. Breadth of basal or tenth segment

=·18 mm. Breadth of sixth segment =·155 mm. Breadth of second segment =·10 mm. Height of first segment =·07 mm. Breadth of first segment =·065 mm.

This form is allied to *D. multicostata*, Zittel, but is about double the size.

Dictyomitra sp. *α*. (Pl. XXXVIII, fig. 5.)

The test is slender, conical, with a very rough surface, and with six segments separated by deep constrictions. Length and breadth of the joints gradually increasing towards the base. Height =·285 mm. Breadth of last segment =·11 mm. Breadth of third segment =·55 mm. Pores not shown.

This form is allied to *D. polypora*, Zittel, from the Cretaceous rocks of Brunswick.[1]

Dictyomitra sp. *β*. (Pl. XXXVIII, fig. 6.)

The test is conical, with six or seven segments. Pores small, circular, in longitudinal rows between small ribs which are prolonged below the base, forming a crenate margin. Height =·19 mm. Breadth of basal segment =·09 mm.

Dictyomitra sp. *γ*. (Pl. XXXVIII, fig. 7.)

The test is long and narrow, conical, with eight segments. The first segment is dome-shaped. Total height =·20 mm. Greatest breadth of basal segment =·09 mm. Breadth of first segment =·03 mm.

Dictyomitra sp. *δ*. (Pl. XXXVIII, fig. 8.)

The test is conical, slightly ventricose, with five segments. There are indications of pores between the segments. Height of test =·125 mm. Breadth of basal segment =·06 mm.

Dictyomitra pagoda, sp. nov. (Pl. XXXVIII, fig. 9.)

The test is large, conical, with seven segments of uniform height. The first segment is sharply conical. The segments at the upper part of the test are studded with tubercular prominences.

It is uncertain whether the hexagonal pores are original, or due to corrosion. Height of test =·31 mm. Height of segments =·05 mm. Basal segment slightly smaller than the one above. Greatest breadth =·14 mm.

This form differs from *D. tiara*, Pl. XXXVIII, fig. 4, in the conical apex, less inflated segments, smaller size, and the presence of tubercles.

Dictyomitra regularis, Perner. (Pl. XXXVIII, fig. 10.)

Test large. The upper portion is regularly conical. The segments number either eight or nine, the lowest three being somewhat inflated. The surface is rough, and the pores are secondary. Height of test =·31 mm. Breadth of basal segment =·10 mm. Breadth of segment next to the base =·115 mm.

[1] Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxviii (1876) p. 75 & pl. ii, fig. 1.

This form agrees in outline with *D. regularis*, Perner, which is figured in section only in ' O Radiolariich, etc.' Sitz. Böhm. Gesellsch. Wissensch. 1891.

Dictyomitra sp. ε. (Pl. XXXVIII, fig. 11.)

The shell is broadly conical, smooth, with five segments of about uniform height. Very fine reticulation, probably secondary. Height of test =·20 mm. Breadth of last segment =·11 mm.

A form very similar to this occurs in the St. Pierre Shales, Yankton (S. Dakota).

Dictyomitra sp. ζ. (Pl. XXXVIII, fig. 12.)

Test with an oval outline, constricted somewhat at the base. Number of segments uncertain. The pores are hexagonal and arranged in slanting rows, but it is doubtful whether they are original or due to corrosion. Height of test =·16 mm. Greatest breadth =·08 mm. Breadth of base =·06 mm.

Order **STEPHOIDEA.**

Genus *Zygostephanus*, Hæckel.

Coronida with four large simple lateral gates, without basal gate and lattice-work. Skeleton composed of two meridional rings perpendicular one to the other.

Zygostephanus aculeatus, Rüst? (Pl. XXXVIII, fig. 13.)

This form is very closely allied, if not identical with *Z. aculeatus*, Rüst, but is not quite so large as his form. It is figured in 'Palæontographica' vol. xlv (1898) pl. vii, fig. 13 & p. 37. Greatest breadth =·43 mm.

The genera, and the number of species in each genus, of the radiolaria found in Chalk-flints at Coulsdon, Surrey, may now be tabulated as follows:—

Sub-class SPUMELLARIA.

Order Sphæroidea.

		Species.
Genus	*Cenosphæra*	2
	Stylosphæra	1
	Trilonche	1
	Acanthosphæra	2

Order Prunoidea.

Genus	*Lithapium*	1

Order Discoidea.

Genus	*Theodiscus*	1
	Spongotripus	2
	Trochodiscus	1
	Uncertain	4
	Coccodiscus	1
	Trigonocyclia	2

		Species.
Genus	*Rhopalastrum*	4
	Trigonactura	1
	Hagiastrum	1
	Stauralastrum	2

Sub-class NASSELLARIA.

Order Cyrtoidea.

Genus	*Cyrtocalpis*	2
	Dicolocapsa	1
	Lithocampe	1
	Dictyomitra	10

Order Stephoidea.

Genus	*Zygostephanus*	1

41 species,
belonging to 20 genera.

EXPLANATION OF PLATES XXXVII & XXXVIII.

[The specimens figured are, with one exception, drawn to the same scale of 200 diameters.]

Plate XXXVII.

Fig. 1. *Cenosphæra* sp.
2. ,, *gregaria*, Rüst.
3. *Stylosphæra* sp.
4. *Trilonche* sp.
5. *Acanthosphæra* sp. *a*.
6. ,, sp. *β*.
7. *Lithapium* sp.
8. Uncertain, probably *Cyphinus* sp.
9. *Theodiscus* sp.
10. *Spongotripus pauper (?)* Rüst.
11. ,, sp.
12. *Trochodiscus* sp.
13. Uncertain.
14. ,,

Fig. 15. Uncertain.
16. *Cyrtocalpis* cf. *compacta*, Hæckel.
17. *Coccodiscus* sp.
18. *Rhopalastrum* sp. *δ*.
19. ,, sp. *β*.
20. *Trigonocyclia* sp. *a*.
21. *Lithocampe* sp.
22. *Trigonactura armata*, sp. nov.
23. *Rhopalastrum* sp. *γ*.
24. *Trigonocyclia* sp. *β*.
25. *Cyrtocalpis* sp.
26. *Rhopalastrum* sp. *a*.
27. *Hagiastrum* sp.
28. *Dicolocapsa* sp.

Plate XXXVIII.

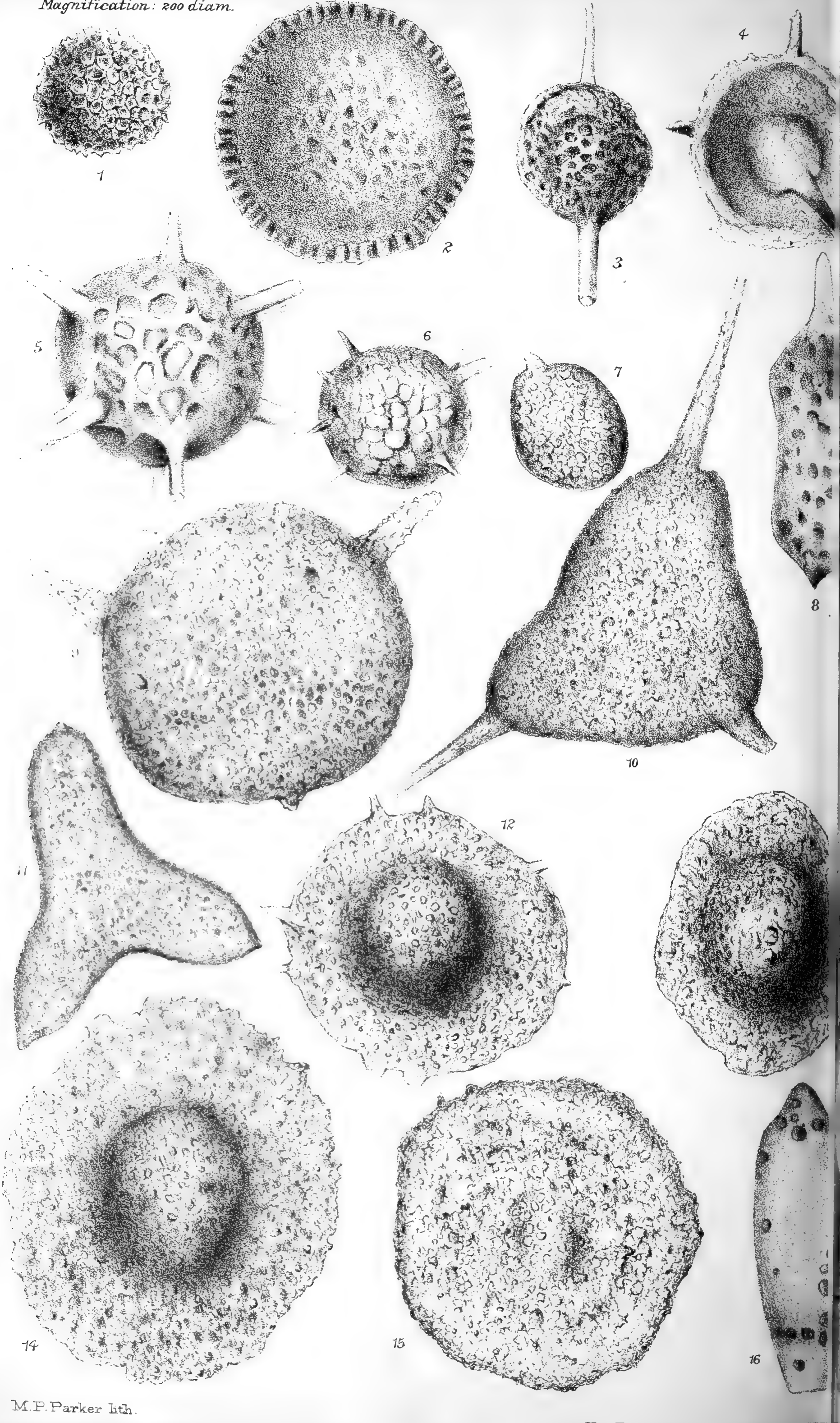
Fig. 1. *Stauralastrum venustum*, sp. nov.
2. ,, sp.
3. *Dictyomitra multicostata*, Zittel.
4. ,, *tiara*, sp. nov.
5. ,, sp. *a*.
6. ,, sp. *β*.
7. ,, sp. *γ*.
8. ,, sp. *δ*.
9. ,, *pagoda*, sp. nov.
10. ,, *regularis*, Perner.
11. ,, sp. *ε*.
12. ,, sp. *ζ*.
13. *Zygostephanus aculeatus (?)* Rüst. ×100 diam.

Discussion.

The President, Prof. Sollas, Dr. W. F. Hume, and Mr. G. E. Dibley spoke.

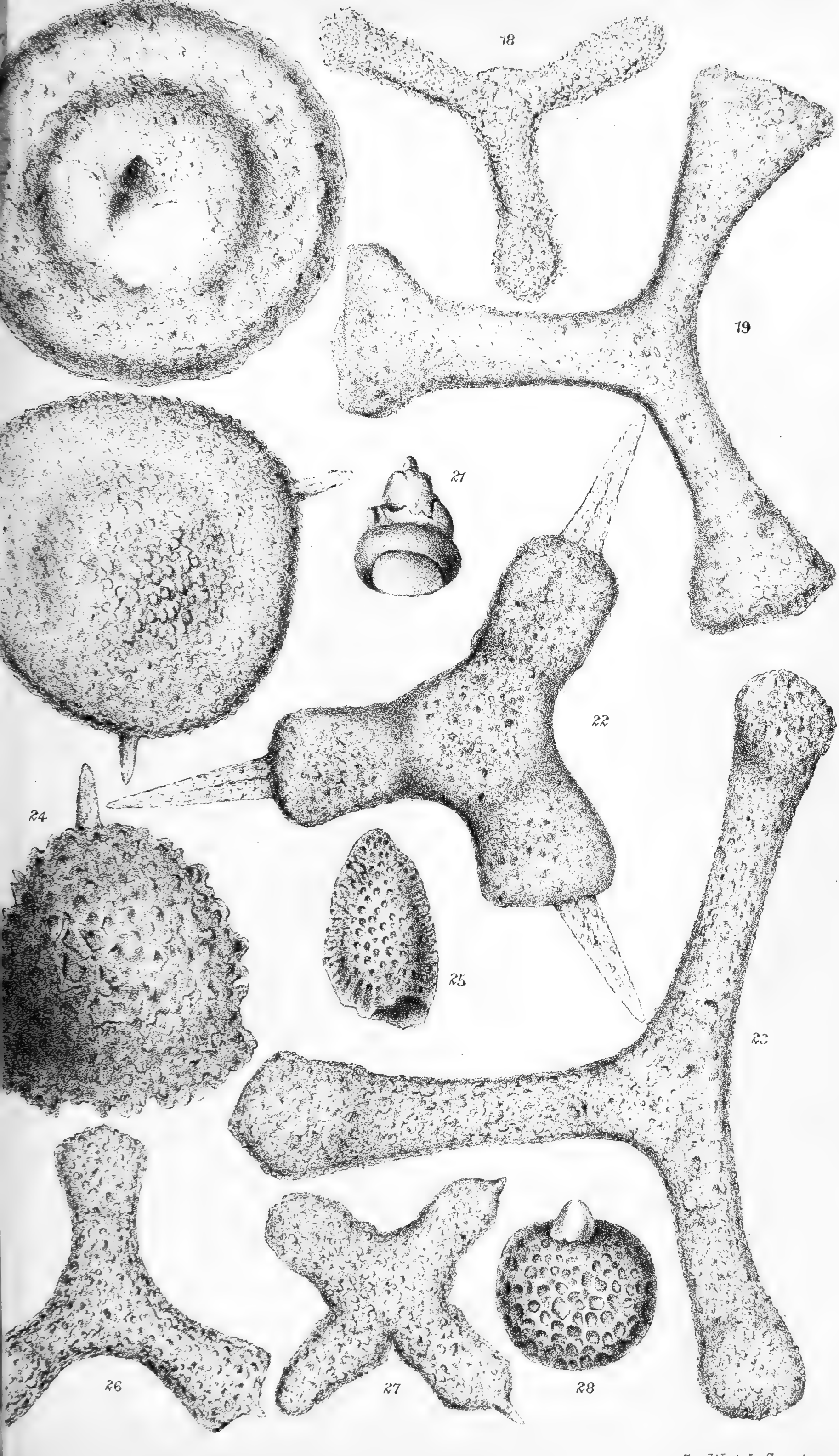
The Author expressed his thanks to the Society for giving him the opportunity of reading the paper. He said that the fossil radiolaria were mounted in stiff glycerine-jelly, as Canada-balsam rendered them almost invisible. He drew attention to some flints similar to those from which the radiolaria were obtained, and to some fossils from Coulsdon among which were some specimens of *Micraster cor-bovis* (Forbes).

Magnification: 200 diam.



M.P. Parker lith.

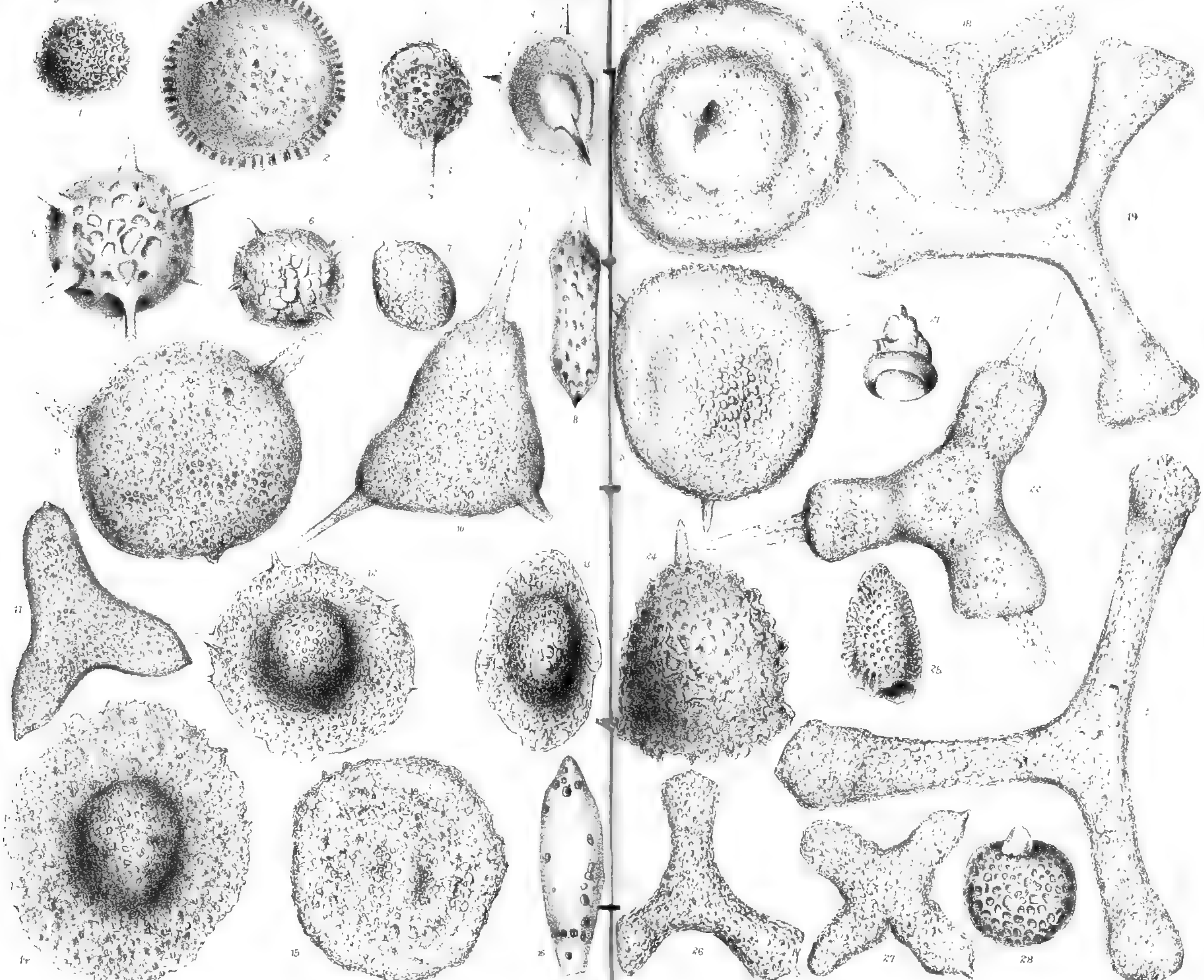
RADIOLARIA FROM THE



CHALK OF COULSDON.

Geo. West & Sons imp.

Magnification 200 diam.

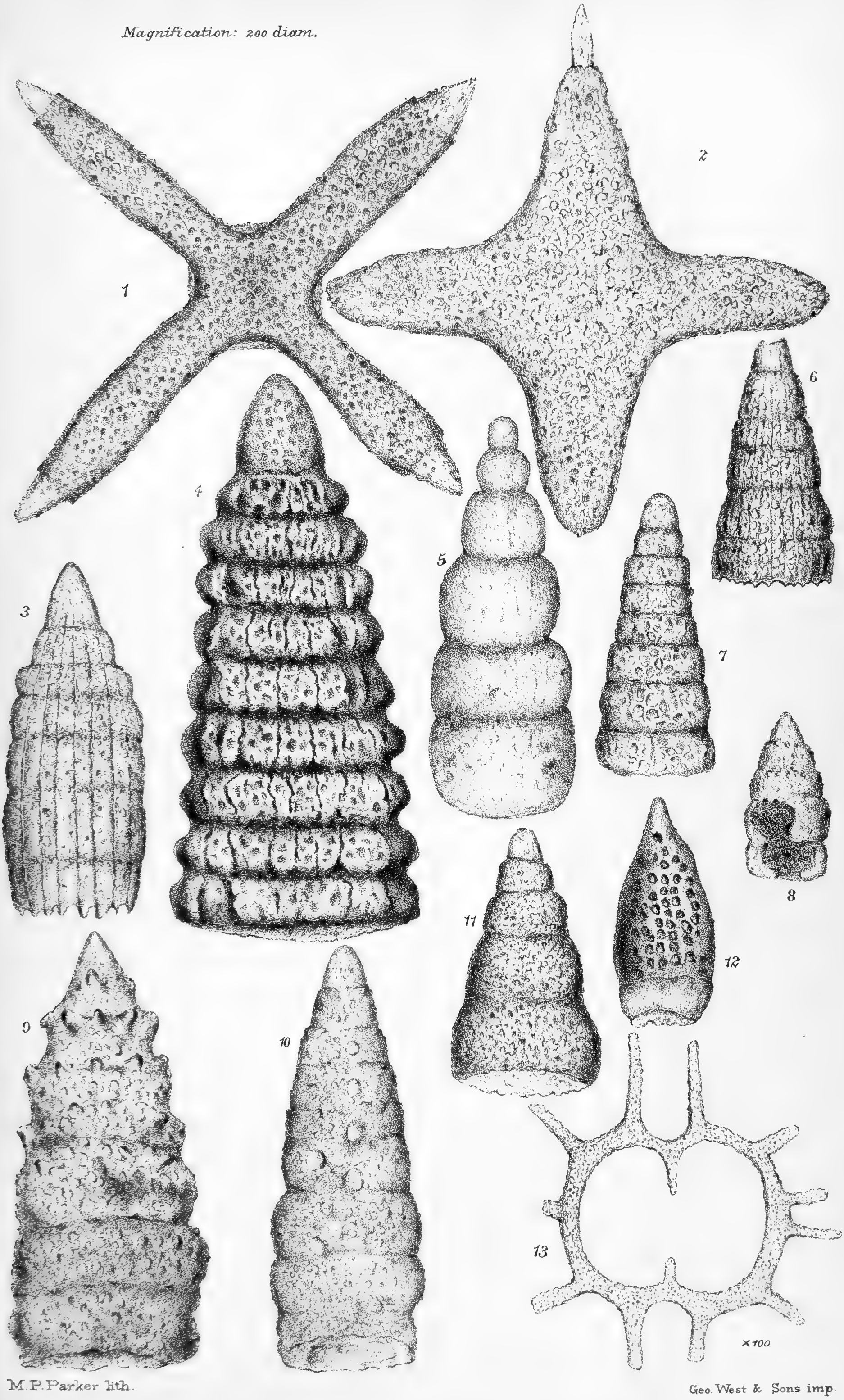


M. P. Parker lith.

RADIOLARIA FROM THE UP. CHALK OF COULSDON

Geo. West & Sons imp.

Magnification: 200 diam.



M. P. Parker lith. Geo. West & Sons imp.

RADIOLARIA FROM THE UPPER CHALK OF COULSDON.

37. *The* Pliocene Deposits *of the* East *of* England.—Part II: *The* Crag *of* Essex (Waltonian) *and its* Relation *to that of* Suffolk *and* Norfolk. By F. W. Harmer, Esq., F.G.S. *With a* Report *on the* Inorganic Constituents *of the* Crag. By Joseph Lomas, Esq., F.G.S. (Read May 9th, 1900.)

Contents.

I. Introductory.

Searles V. Wood, as is well known, regarded the shell-bed of Walton-on-the-Naze, with its strongly-marked southern fauna, as older than any other part of the Red Crag, grouping the rest of that formation, in which northern shells occur more or less abundantly, under the name of the Crag of Sutton and Butley,[1] although he believed that of the latter locality to be the newer of the two.[2] Prestwich, on the other hand, maintained that all the Red Crag beds, and to some extent the Norwich Crag also, were contemporaneous[3]; and this view is, I believe, still held by no less an authority than the ex-President of the Geological Society.[4] In the face of such a difference of opinion, it seemed to me necessary to return to the subject, in order that, if possible, some more definite conclusions might be arrived at. In the hope therefore of obtaining further evidence as to the correct classification of these beds, I have spent my leisure time during the past five or six years in revisiting every part of the Crag district, and in the examination of all the more important collections of Crag fossils.

The view that the Red Crag deposits are all of the same age appears, at first sight, not unreasonable, though it is not so easy to understand why those of the Norwich Crag should have been grouped with them. As to the former, many, perhaps most, of their more characteristic mollusca are found in every part of the formation, so that lists of fossils from different localities present a striking resemblance to each other.

[1] 'Suppl. Crag Moll.' Monogr. Pal. Soc. (1872–74) p. 203, & elsewhere. S. V. Wood, Jun. and I expressed a similar opinion in the same work, p. vii. At that time we did not see our way satisfactorily to separate the Sutton and Butley deposits.

[2] Quart. Journ. Geol. Soc. vol. xxii (1866) p. 538.

[3] *Ibid.* vol. xxvii (1871) p. 325. Prestwich believed, however, that in many of the Red Crag exposures an upper division could be traced, but he did not attempt to show that it contained mollusca different from those of the underlying beds.

[4] Proc. Geol. Assoc. vol. xv (1898) p. 443.

The evidence which I have collected shows, however, that some of these species are not equally common throughout, and that horizons in the Crag may be established whereat certain forms, extinct or southern for the most part, seem to have been dying out, or to have disappeared; while others, generally recent or northern, were appearing for the first time, or becoming more abundant. Moreover, the proportion between recent and extinct, and northern and southern shells at different spots varies considerably, all the evidence pointing consistently in the same direction.

Speaking generally, the molluscan fauna of any Red or Norwich Crag locality resembles most nearly that of the parishes immediately adjoining it; while from Walton-on-the-Naze, at the southern limit of the district, to Weybourn, on the northern coast of Norfolk, the Crag-beds assume a more recent and a more boreal character as we trace them northward.[1]

That these deposits arrange themselves in horizontal rather than in vertical sequence is shown by the fact that, so far as the evidence goes, the more recent Red Crag strata are not underlain by those of an earlier stage, nor do Norwich Crag beds ever rest upon Red Crag.[2] For example, the former were pierced in borings at Southwold[3] and Beccles,[4] and proved to be 147 feet and 80 feet thick respectively at those places; but at neither was the latter met with, the mollusca obtained being all of the usual Norwich Crag type. Instances of the overlapping of beds belonging to the same division of the Crag, but to a slightly different horizon, sometimes occur, however, as at Walton and Beaumont, and at the Norwich Crag pit on Bramerton Common.

In Holland, the Pliocene beds, perhaps nearly 1000 feet thick, which represent the ancient delta of the Rhine and its affluents, include a vertical and apparently continuous succession of strata from Diestian to Amstelian. In Belgium, on the contrary, deposits originating nearer to the then existing margin of the North Sea, and belonging to distinct and disconnected horizons, occupy, more or less, different areas: periods of disturbance having been followed by periods of repose, during which only deposition took place in that region.

Similarly, the Red Crag deposits of East Anglia do not form an unbroken sequence, but may be referred to three (or perhaps to four) principal stages, of which the faunas, although possibly not entirely contemporaneous, are sufficiently distinct to justify their separate classification.[5]

The term Red Crag, including, as I believe it does, beds differing considerably in age, is vague, and when we attempt to correlate the East Anglian deposits with those of other countries, inconvenient:

[1] The Coralline Crag and the estuarine Chillesford Beds are, however, for obvious reasons, exceptions to this rule.

[2] See footnote, p. 721. [3] Mem. Geol. Surv. (1887) Southwold p. 79.

[4] *Ibid.* Norwich (1881) p. 156.

[5] The deposition of the Norwich Crag was, however, as I shall endeavour to show farther on, of a similarly continuous character to that of the Dutch deposits.

the Scaldisian zone of Belgium, for example, with its southern fauna, representing one portion of it, and the Amstelian of Holland, in which arctic shells occur, another. It seems desirable, therefore, while retaining it for general use, to adopt for its various horizons some more definite and distinctive names. In a paper read before the British Association at Dover, in 1899, published in abstract only, I proposed the classification tabulated on p. 708 for the Pliocene deposits of the East of England.

The Coralline Crag (Gedgravian[1]) has been hitherto referred to the Older, and the Red Crag, including the Walton zone, to the Newer Pliocene period, the former being regarded as equivalent to the Plaisancian deposits of Italy.[2]

At the time of the publication of Wood's Supplement in 1872, there seemed good reason for this classification, as more than one-half of the species known from the Coralline Crag had not then been found in the Red, but a large number of these have since been obtained from the latter (50 by myself during the last three years at Beaumont and at a new locality at Little Oakley, in Essex); and increased knowledge of these formations has always tended to diminish rather than to emphasize the distinction between them.

Most of the characteristic Coralline Crag species are now known to occur in the Waltonian Beds, the exceptions being principally either forms which are rare or unique in the Coralline Crag, or small shells that might have been brought from some distance into the Crag area by currents from the south, which I think prevailed at the earlier period. The principal difference between the Coralline and Walton horizons is that the Waltonian Beds contain a number of mollusca which, during the interval separating the two periods, had invaded the Crag basin, presumably from the north, owing probably to the opening-up of communication with northern seas by the tectonic movements referred to in my former papers.[3] A reference to the synoptical analysis on p. 725 will show that palæontologically there is not more difference between the Coralline and Walton Crags than there is between the latter and other later zones. I doubt therefore whether the Coralline Crag is as old as the Plaisancian,[4] and am inclined to draw the line separating

[1] Gedgrave is the only locality in the Crag district where none but Coralline Crag deposits occur.

[2] See, for example, C. Reid, 'Pliocene Deposits of Britain' Mem. Geol. Surv. (1890) p. 223.

[3] With one or two exceptions, the Red Crag forms unknown from the Coralline Crag cannot be regarded as modified descendants of species belonging to the latter, and they must therefore have emigrated from other seas. Some of these, however, had reached the Belgian area as early as the Diestian Period: as, for example, *Nassa reticosa*, *Natica hemiclausa*, *Astarte obliquata*, and *Tellina Benedenii*. Mr. P. F. Kendall informs me that he has found a specimen of *Nassa reticosa* in the Coralline Crag at Gedgrave.

[4] Even allowing for the difference in latitude, the correspondence between the fauna of the Coralline Crag and that of the Plaisancian does not seem to me to be very close. From time to time I have made collections from the latter at Bordighera, Cannes, Biot, etc.; but I found that comparatively few of the fossils so obtained, presumably the characteristic forms of these deposits, are known from the Coralline Crag.

Proposed Classification of the Pliocene Deposits of the East of England.

			English Localities.	Belgian and Dutch Equivalents.
NEWER PLIOCENE.				
Cromerian.	Cromer Beds (so-called Forest-bed Series). Zone of *Elephas meridionalis*. Freshwater and estuarine.)		Kessingland, Corton, Norfolk coast from Happisburgh to Weybourn.	
Weybournian.	Zone of *Tellina balthica*. (Marine.)		Crostwick, Rackheath, Wroxham, Belaugh, Weybourn, and the Cromer coast.	
Chillesfordian.	Chillesford Clay and Sand. Zone of *Leda oblongoides*. (Estuarine.)		Chillesford. Various localities in Norfolk and Suffolk.	
Icenian.	Norwich Crag. (Marine.)	Upper Division. Zone of *Astarte borealis*.	Easton Bavent, Yarn Hill, Aldeby, Bramerton, Thorpe near Norwich, Postwick, Brundall, Horstead, Coltishall, Burgh, Wroxham.	
		Lower Division. Zone of *Mactra subtruncata*.	Aldeburgh, Thorpe (Suffolk), Dunwich, Bulchamp, Southwold, Beccles, Ditchingham.	
Butleyan.	Red Crag. (Marine.)	Zone of *Cardium grœnlandicum*.	Sudbourn, Chillesford, Iken, Butley, Boyton, Bawdsey, Alderton, Hollesley.	Amstelian. Upper part.
Newbournian.		Zone of *Mactra constricta*.	Suffolk, between the Rivers Orwell & Deben, and Ramsholt, Sutton, Shottisham.	
?		?	Bentley, Tattingstone, and the district between the Rivers Stour & Orwell.	Amstelian. Lower part.
Waltonian.		Oakley Horizon. Zone of *Mactra obtruncata*.	Beaumont, Oakley, Dovercourt, Harwich.	Poederlian.
		Walton Horizon. Zone of *Neptunea contraria*.	Beaumont, Walton-on-the-Naze.	Scaldisian—Zone à *Trophon antiquum* (*Chrysodomus contraria*).
Gedgravian.	Coralline Crag.	Zone of *Mactra triangula*.	Tattingstone, Sutton, Ramsholt, Boyton, Gedgrave, Sudbourn, Orford, Iken, Aldeburgh.	Casterlian—Zone à *Isocardia cor*.
OLDER PLIOCENE.				
Lenhamian.	Lenham Beds.	Zone of *Arca diluvii*.	Lenham, Harrietsham, Charing, Paddlesworth, Folkestone.	Diestian.
	Boxstone Fauna.		Base of Red Crag. Base of Coralline Crag at Sutton.	Waenrode Beds?

It must be understood that the species mentioned above as specially characteristic of certain horizons are only l o c a l l y so. Most of them are species still living, though not now, with two exceptions, in the Anglo-Belgian area. The distribution of mollusca during the Pliocene period, as at present, was largely a matter of latitude.

the Newer from the Older Pliocene between the Lenham Beds (containing *Arca diluvii*,[1] and other characteristic Italian Pliocene or Miocene shells of the North Sea basin) and the Coralline Crag, regarding the latter as the oldest member of a more or less continuous and closely connected series of Newer Pliocene age.

The Gedgravian Beds seem to be approximately equivalent to the Belgian zone à *Isocardia cor*, as suggested by M. Van den Broeck. The Lenham and Folkestone Beds, on the other hand, not only closely resemble the sands of Diest and Louvain lithologically, but are connected stratigraphically with them by a more or less continuous chain of outliers always occupying high ground, as pointed out by that observer. He formerly separated the Antwerp Beds à *Isocardia cor* from the Diestian Sands under the term Casterlien[2] (originally proposed by Dumont), and I suggest that it might be desirable to revive that classification. If, as I think, the Lenham deposits are distinct from the Coralline Crag, the zone à *Isocardia cor* may be equally distinct from the ferruginous sandstones of Belgium.

II. The Crag of Essex—Waltonian. (See Map on p. 710.)

The Red Crag beds for which I propose the term Waltonian are confined to the county of Essex, and are distinguished, as is the Walton deposit, by the strongly marked southern facies of their molluscan fauna, and especially by the abundance of the southern species, *Neptunea contraria*, and the absence, except in the Oakley sub-zone as explained farther on, of the dextral form, *Neptunea antiqua*,[3] and its northern allies *N. despecta* and *N. carinata*. The study of the comparative abundance of these two groups at different horizons in the Crag is of considerable importance. The sinistral species, so characteristic of the Essex Crag, becomes less abundant at the various exposures in Suffolk as we trace them northward, and it is rarely met with in Norfolk. The dextral shell, on the contrary, almost unknown at the Walton horizon, is increasingly

[1] I am not aware that any species, which is as specially characteristic of the Coralline Crag as *Arca diluvii* is of the Lenham Beds, can be pointed out as absent from Walton.

[2] 'Diestien, Casterlien & Scaldisien,' Ann. Soc. Roy. Malac. Belg. vol. xvii (1882) Bull. pp. ciii–cviii.

[3] I have given elsewhere, Proc. Internat. Congr. Zool. Cambridge (1898) p. 222, my reasons for believing that *Neptunea antiqua* and *N. contraria* are not varieties of the dextral form as now generally supposed, but, as originally described by Linnæus, distinct species. These migrated separately into the Crag area from the north, *N. contraria* arriving at an earlier period, and penetrating during the Pliocene epoch farther southward than *N. antiqua*. At present, moreover, the sinistral shell is not known living farther north than Vigo Bay, on the western coast of Spain; while the dextral *N. antiqua*, and especially its carinated representatives, have a northern range. The reversed specimens of *N. antiqua* occasionally met with in British seas are doubtless monstrous varieties of the dextral shells with which they occur, and which they closely resemble. The sinistral shells of the Crag, on the contrary, are allied to the species now living in Vigo Bay, and to *N. sinistrorsa* of the Sicilian Pliocene. No reversed (that is, dextral) specimens of the Crag form *N. contraria* have ever been met with.

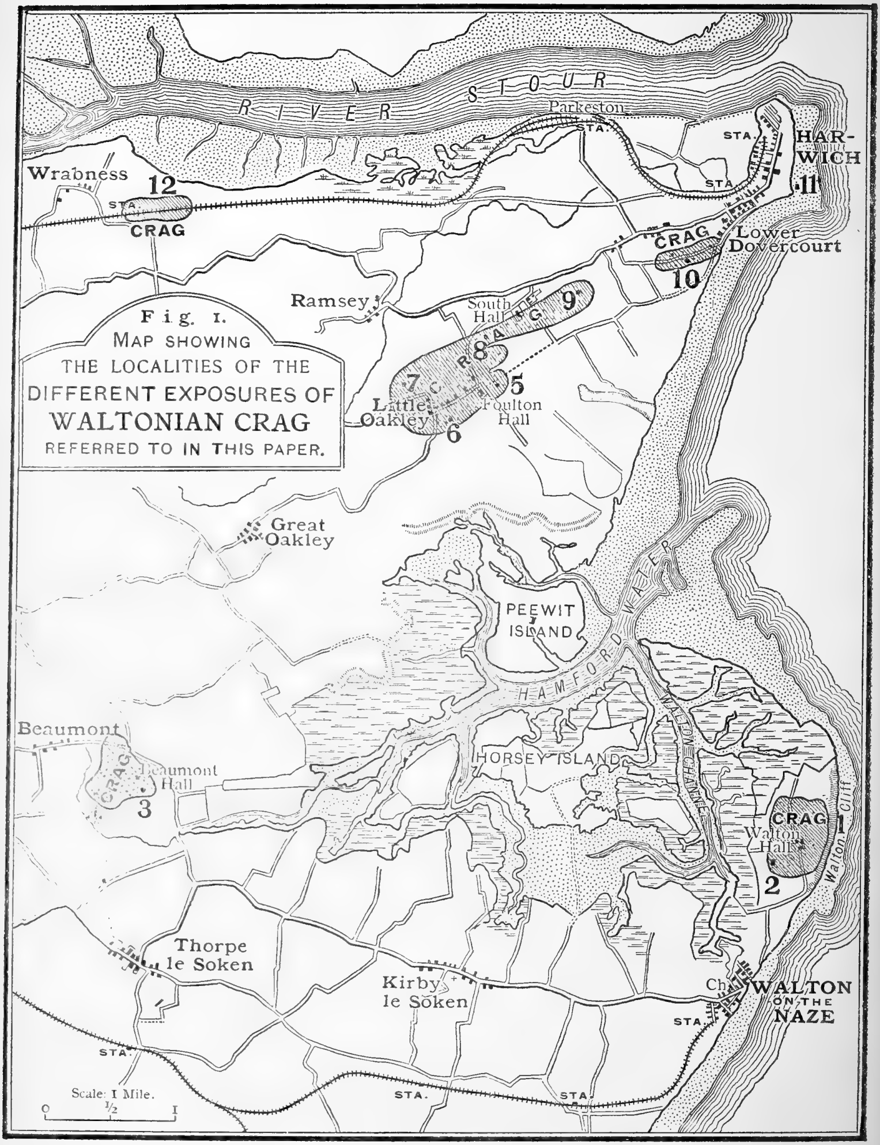
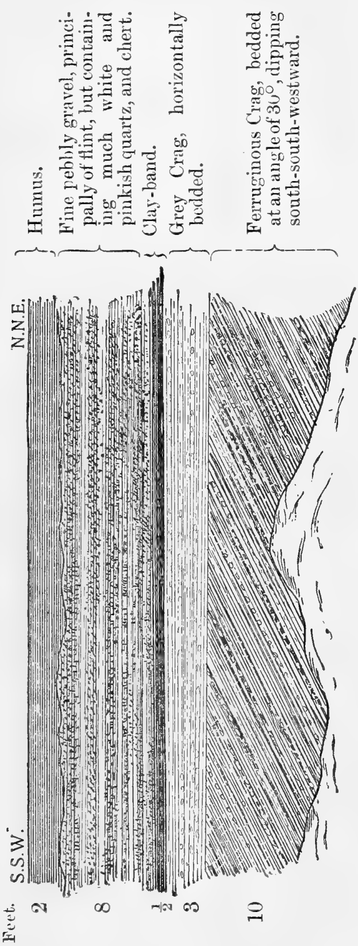


Fig. 1.
MAP SHOWING
THE LOCALITIES OF THE
DIFFERENT EXPOSURES OF
WALTONIAN CRAG
REFERRED TO IN THIS PAPER.
RIVER STOUR
Parkeston
STA.
HARWICH
11
Wrabness
12
CRAG
Lower Dovercourt
10
Ramsey
South Hall
9
8
CRAG
7
5
Little Oakley
Foulton Hall
6
Great Oakley
PEEWIT ISLAND
HAMFORD WATER
WALTON CHANNEL
Beaumont
CRAG
Beaumont Hall
3
HORSEY ISLAND
Walton Hall
2
1
Walton Cliff
Thorpe le Soken
Kirby le Soken
Ch.
WALTON ON THE NAZE
Scale: 1 Mile.
0
½
1

common in the northern part of the Crag area; and the varying proportion between the two at different localities coincides everywhere with that between the southern and northern, and the extinct and recent species of mollusca.

The most important and best-known exposure of Crag in the county of Essex is that of the long cliff-section at Walton-on-the-Naze (marked 1 on the map, fig. 1, p. 710).[1] There is also a large pit near that town at the spot marked 2, which is now overgrown, but it could be easily opened if permission were obtained.[1]

Fig. 2.—*Section at Walton Cliff.*



In his First Supplement to the 'Monograph of the Crag Mollusca'[2] Searles V. Wood gave a list of 148 species of mollusca known to him from Walton, a large proportion of them being extinct or southern forms; and in his Second and Third Supplements[3] about 50 more were added, principally on the authority of the late Robert Bell. Some years later, Mr. P. F. Kendall worked at Walton for a considerable time, increasing the list of shells to about 320.[4] His researches, with those of other observers, have, however, confirmed Wood's view of the southern as well as the older character of the Walton fauna.

Unfortunately, at present and for some years past the cliff-section has been obscured by talus, and visible only at a few isolated spots;

[1] It would be more useful, and more interesting also, if collectors would devote their efforts to these less-known Crag localities, rather than to the few pits to which continuous attention has been paid during so many years.

[2] Monogr. Pal. Soc. (1872) pp. 203–19. [3] Monogr. Pal. Soc. (1879 & 1882).

[4] Mr. Kendall has very generously offered to allow me to incorporate this list with that of the species obtained by me from Beaumont and Little Oakley, which will very much increase the value of the latter to students of the Crag.

but fig. 2 (p. 711) represents a portion of it exposed at two localities, at no great distance apart, the succession of beds being the same at each.

The upper part of the Crag now shown at this place is of a grey colour, and is horizontally stratified; while the lower part is ferruginous, and obliquely-bedded at an angle of about 30°, the laminæ dipping south-south-westward. This oblique bedding was noticed by Searles V. Wood, Jun. at Walton and elsewhere thirty-six years ago,[1] and it has, I think, an important bearing on the question of the conditions under which the Red Crag originated. An unstratified shell-bed, described by him in the same paper as resting upon the London Clay, with the remains of mollusca in an undisturbed position of growth, is not now visible.

The upper part of the cliff-section is occupied by a bed of sandy gravel, made up chiefly of flint, but containing also pebbles of various kinds of quartz (pink and white), and of chert. This is underlain by a band of grey sandy clay, which has been considered as possibly of Chillesford age.[2] The clay and the gravel are, however, more or less conformable one to the other and to the underlying Crag, and I am inclined to think that both of the former may be of Red Crag age. This view has been recently confirmed by my friend Mr. Lomas, who has discovered that the sandy portion of the gravel is identical in composition with that of the Crag.

From Walton southward the cliff is composed of London Clay, with a few obscure traces of gravel over it; between Little Holland and Clacton-on-Sea similar pebbly beds occur in the coast-section, but in much greater thickness than at Walton, extending for 3 miles or more to the north of Clacton (see map, fig. 3, p. 714). I suggest that these gravels may be either fluviatile or estuarine, brought down by a river which ran from the south-west at some period later than that of the deposition of the Walton shell-bed, when the southern margin of the Crag sea had retreated northward.[3]

The species of mollusca which I consider most characteristic of the Walton Crag are as follows:—

Cypræa avellana.
—— *europæa.*
Voluta Lamberti.
Columbella sulcata.
Nassa labiosa.
—— *propinqua.*
—— *elegans.*
—— *granulata.*
—— *reticulata* and varieties.
Buccinopsis Dalei
Buccinum undatum.
Purpura lapillus var. *intermedia.*
—— *tetragona* var. *alveolata.*
Trophon (Neptunea) contrarius.
—— (——) *costifer.*
—— (*Sipho*) *gracilis.*
—— (——) *Olavii.*
—— (——) *muricatus.*
Pleurotoma mitrula.
Cerithium tricinctum.
Turritella incrassata.
Lacuna subaperta.
Natica catenoides.
—— *hemiclausa.*
—— *millepunctata.*
Trochus cineroides.

[1] Ann. & Mag. Nat. Hist. ser. 3, vol. xiii (1864).

[2] See Mem. Geol. Surv. (1877) 'Eastern End of Essex (Walton-on-the-Naze & Harwich)' p. 13.

[3] If this view be correct, the clay-bed is not of Chillesford age.

Trochus noduliferens.
—— *subexcavatus.*
—— *Adansoni.*
—— *Montacuti.*
Fissurella græca.
Emarginula fissura.
Calyptræa chinensis.
Capulus ungaricus.
Tectura virginea.
Actæon Noæ.
Conovulus pyramidalis.
Anomia ephippium.
Ostrea cochlear.
Pecten opercularis.
—— *pusio.*
Mytilus edulis.
Pectunculus glycimeris, especially var. *subobliquus.*
Nucula lævigata.
Montacuta bidentata.
Scintilla ambigua.
Lucina borealis.
Cardita corbis.
—— *scalaris.*
—— *senilis.*
Cardium edule.
—— *Parkinsoni.*
Cyprina islandica.
Astarte obliquata.
—— *Galeottii.*
—— *Burtinii.*
Woodia digitaria.
Artemis lentiformis.
Mactra arcuata.
Solen ensis.
—— *siliqua.*
—— *gladiolus.*
Corbula gibba.
Corbulomya complanata.
Pholas crispata.
—— *cylindracea.*

The majority of the foregoing species are either extinct or southern forms.

A number of northern or recent species, which became more or less common in the later beds of the Red Crag, are moreover absent or rare at Walton; of these I may mention:—

Buccinum grœnlandicum.
Trophon (Neptunea) antiquus (dextral).
—— *despectus.*
—— *scalariformis.*
—— *altus.*
Purpura lapillus (the existing form).
Cancellaria viridula.
Turritella terebra.
Scalaria grœnlandica.
Littorina littorea.
Natica clausa.
—— *catena.*
—— *grœnlandica.*
Trochus formosus.
—— *tumidus.*
Modiola modiolus.
Nucula Cobboldiæ.
—— *tenuis.*
Leda oblongoides.
—— *lanceolata.*
Cardium angustatum.
—— *grœnlandicum.*
Astarte compressa.
—— *sulcata.*
Tellina obliqua.
—— *prætenuis.*
Mactra ovalis.
—— *constricta.*

None of the foregoing species are known from the Crag of Normandy, or from any Older Pliocene beds south of Great Britain.

A very few specimens only of some of them have been found at Walton; but they are the rare exceptions, not the rule, and were the vanguard, so to speak, of the molluscan army which at a subsequent period invaded the Crag basin from the north.

Adopting, as I have always done, Wood's opinion as to the comparatively early age of the Walton Crag, and its marked distinction from that of Suffolk, it seemed to me important, as a crucial test of the hypothesis that the upper Crag deposits were the littoral accumulations of a sea gradually retreating northward, to re-examine the district between Walton and the estuary of the Stour, in order to see whether any beds of intermediate character could there be found, which might serve to bridge over the gap separating the Walton Crag from that of Suffolk.

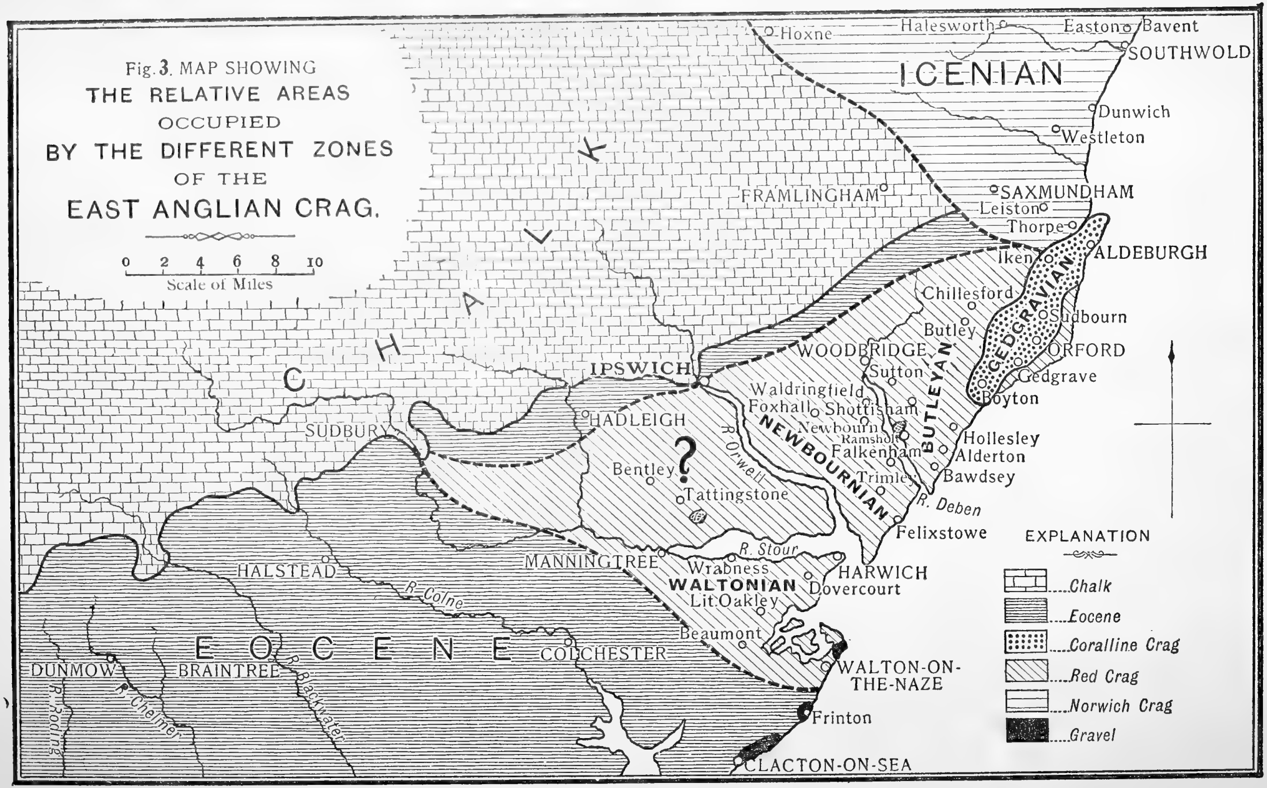


Fig. 3. MAP SHOWING THE RELATIVE AREAS OCCUPIED BY THE DIFFERENT ZONES OF THE EAST ANGLIAN CRAG.

Note: South of the River Stour the Red Crag has been much denuded.

I was fortunate enough to find such a deposit in the first instance, at Beaumont, 5 miles west of Walton. The section at that locality, described more than fifty years ago by the late John Brown of Stanway, has been closed for many years, but it has been recently reopened.[1] Brown obtained about 100 species of mollusca from this spot, and his list, originally appearing in a pamphlet printed for private circulation, was afterwards republished by Mr. Whitaker in his Survey Memoir.[2] Unfortunately the names of *Astarte borealis* and *Tellina lata*, arctic shells characteristic of the newest horizons only of the Crag, were included,[3] and no distinction was made between rare and abundant forms, so that the Beaumont deposit has been referred, not without justification, to the latest part of the Red Crag.[4] When studied on the spot, however, it will be clear, I think, that, though possibly slightly newer, it is of similar age to that of the Walton bed. I have lately obtained more than 260 species from Beaumont, and I find that, with very few exceptions, those mentioned on pp. 712–13 as characteristic of the Walton Crag, occur there more or less abundantly.

While the molluscan fauna of the Beaumont Hall pit resembles so closely that of Walton Cliff, there are some points of difference between the two. A few northern shells are present at the former locality which are wanting or are exceedingly rare at the latter. *Natica clausa* is found occasionally at Beaumont, but only one specimen, so far as I know, has been recorded from Walton. *Tellina prætenuis*, allied to, though distinct from, the arctic form, *T. lata*, is regarded as an extinct species ; but it came into the Crag sea with the northern mollusca, and waxed abundant in it as they did. It is not uncommon at Beaumont, though almost unknown at Walton. The general facies of the Beaumont fauna, however, is decidedly southern.[5]

Through the kindness of A. H. Stanford, Esq., of Beaumont Hall, I was allowed to open a hole at a spot marked 4 on the map (fig. 1, p. 710), near the south-western limit of the Beaumont outlier. This showed from 5 to 6 feet of Crag, resting upon the London Clay, the junction of the two dipping sharply south-westward. The surface of the ground slopes rapidly in the same direction, with the result

[1] There is an inn at Thorpe-le-Soken where fairly comfortable accommodation may be obtained. From Thorpe a short cut strikes across the fields to Beaumont. Leave to visit the Crag-pit should, however, be obtained from Mr. Stanford.

[2] Mem. Geol. Surv. (1877) 'Walton-Naze & Harwich' p. 26.

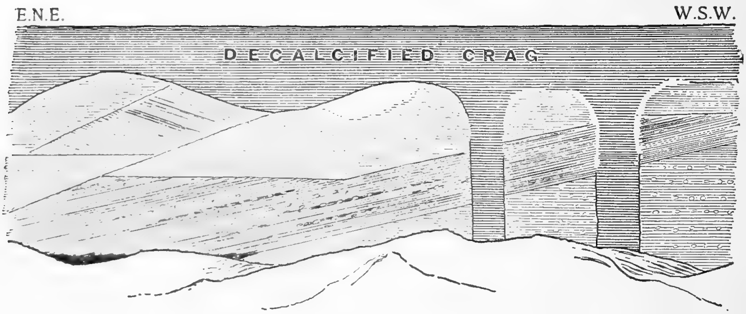
[3] Brown mentions two species of *Tellina* only :— *T. obliquata* and *T. ovata* ; these appear in Mr. Whitaker's list as *T. obliqua* and *T. lata*. The forms present at Beaumont are, however, *T. obliqua* and *T. prætenuis*. The specimens referred by Brown to *Astarte borealis* may have been worn examples of *A. Basterotii*. *A. borealis* has not been found, so far as I know, south of Easton-Bavent, nearly 40 miles from Beaumont, where it occurs in beds of Upper Norwich-Crag age.

[4] Mem. Geol. Surv. (1890) 'Plioc. Dep. of Britain' p. 85.

[5] Two characteristic Coralline Crag and southern species, *Cardita corbis* and *Woodia digitaria*, for example, are present at Beaumont in the most extraordinary profusion.

that the base of the Crag, instead of being water-logged and stained, as at the other pit, is as dry as powder and quite white, having been unaffected by the infiltration which has given to the part above it the usual rusty hue of the Red Crag.[1] From pit No. 4 I obtained several species which I did not notice at No. 3, namely: *Mactra obtruncata* (very common), *Purpura lapillus* var. *intermedia*, with one adult and two or three young specimens of *Neptunea antiqua* (dextral), and of its northern variety *carinata*. These are all characteristic of the still newer deposit at Little Oakley to be described farther on (p. 739). While *Neptunea contraria* is most abundant at Beaumont, the dextral form, *N. antiqua*, is very rare at pit No. 3. With the help of a labourer, about 7 or 8 tons of Crag were sifted there, but only one perfect specimen and one small fragment of the latter species were met with.[2]

Fig. 4.—*Section of Waltonian Crag near Beaumont Hall.*



The fossils have been removed from the upper portion of the Beaumont section by infiltration, but the carbonate of lime so derived has been redeposited on the surface of the unaltered Crag, and along the edges of pipes which are filled with material similar to that of the decalcified portion. The Crag is partly false-bedded, with an east-north-easterly dip, but the inclination of no part of the bedding is so great as that of the beach-like Crag at Walton and elsewhere. The base of the deposit where it rests upon the London Clay is black (see Mr. Lomas's Report, p. 738). Although the Crag outlier caps the summit of a hill, whence the ground slopes rapidly towards Thorpe, water stands constantly at the bottom of the pit, even during the summer, showing that the surface of the underlying London Clay is more or less cup-shaped.

Pursuing my investigations in a northerly direction, I found at

[1] This tends, I think, to show that the staining of the Red Crag has taken place, in some cases at least, in comparatively recent times.

[2] Right-handed specimens are quite unknown to the farm-labourers at Beaumont. This is not only a matter of common observation among them, but they have formulated a theory to account for it: 'Before the Flood, everything was left-handed.'

Foulton Hall, Little Oakley, midway between Beaumont and Harwich (about 4 miles from each place), a shallow section (No. 5 in the map, fig. 1, p. 710), showing only 1 or 2 feet of dirty-looking horizontally-bedded Crag, which, although its existence was known both to S. V. Wood, Jun.,[1] and to Mr. Whitaker,[2] had received hitherto no attention from collectors. It has revealed, however, an exceedingly rich and interesting fauna, generally similar to that of Walton and Beaumont, and distinctly southern. This fauna includes nevertheless a larger proportion of northern forms than is found at those places, representing the somewhat later period before the southern shells had commenced to disappear, when boreal mollusca were beginning to establish themselves, in greater or less abundance, in the Pliocene basin.

As the Crag of Little Oakley appeared to be different in age from anything previously known, I determined to work it out as thoroughly as I could. By the kindness of Gilbert Purvis, Esq., of Foulton Hall, I was allowed to excavate and sift over an area 10 yards in length by 3 in breadth, obtaining in so doing more than 350 species and well marked varieties of fossils,[3] some of them new to science, and many of them known to Wood from the Coralline Crag only.[4] The presence of so large a number of distinct forms in one seam, little more than 12 inches thick, and only 10 yards long, constitutes a striking illustration of the extraordinary richness of the molluscan fauna of the North Sea at that period.[5]

Among the boreal forms present at Oakley I may mention:—*Trophon scalariformis*, *Tr.* (*Sipho*) *gracilis*, and its allies *Tr. Olavii*, *Tr. gracilis* var. *convolutus*, *Tr. Sarsii*, *Tr. Jeffreysianus*, and *Tr. islandicus*, and *Trochus formosus*, which are all more abundant there than they are at Beaumont, as are also *Natica clausa*, *Mactra obtruncata*,[6] *Tellina obliqua*, and *T. prætenuis*. The northern shells, *Trophon barvicensis*, *Admete viridula*, *Scalaria grœnlandica*, *Modiola*

[1] MS. 1-inch map in the Geological Society's Library (about 1864).

[2] Mem. Geol. Surv. (1877) 'Walton-Naze & Harwich' p. 14.

[3] The occurrence, or otherwise, of so-called varieties at the various Crag localities is of considerable importance, and should always be noted. For example, *Purpura lapillus* is said to occur at all horizons of the Upper Crag, but the variety specially characteristic of the Oakley bed [at present undescribed, but which I propose to call *intermedia*] is very different from the existing shell, while that of the much more recent Norwich Crag is identical with it. The distinction between species and varieties is, moreover, quite arbitrary. Many so-named varieties of Crag species, as, for example, those of *Nassa reticosa*, differ more widely one from the other than do other Crag forms which are generally regarded as specifically distinct.

[4] The Crag-pit at Foulton Hall is no longer available: I was compelled to level it down as the work proceeded. I shall be pleased, however, to show my specimens to any student of the Crag, and I propose eventually to place them in the Museum at Norwich.

[5] The present molluscan fauna of the North Sea is much poorer than this. During a recent visit to the shell-beaches of the Dutch coast, I noted less than 30 species, and not more than about 100 have been recorded as now living near the shores of Norfolk, many of them being very rarely met with.

[6] *Mactra obtruncata* is abundant in the upper part of pit No. 4 at Beaumont.

modiolus, and *Astarte compressa* are found at Oakley, though not frequently. On the other hand, the southern forms *Cardita corbis* and *Woodia digitaria* are somewhat less common at Oakley than at Beaumont.

A noteworthy feature of the Oakley fauna is, the occurrence in it, though not abundantly, of *Neptunea antiqua* (dextral). Of the carinated and peculiarly northern forms of this shell I have found there more than a score of examples,[1] principally young, and one of an exceedingly short-spired variety, *brevispira*.[2] These earliest recorded specimens of *N. antiqua* are generally short-spired, and show no signs of approaching the normal Red Crag type of *N. contraria* with which they co-existed, as they ought to do if the one were merely a variety of the other.

The presence at Oakley of *Trochus tricariniferus*, *Pecten Gerardii*, *Lima plicatula* (a single specimen only of each), and other species hitherto known from the Coralline Crag alone, is interesting, as is that of several new species of *Nassa* and *Cardita*, and of *Cancellaria mitræformis* var. *costulata*, the latter closely resembling a shell from the Italian Pliocene. Specimens of *Turritella marginalis* and *T. vermicularis* (fragmentary), also Italian Pliocene shells, have been found, as well as *Natica helicina*, a Miocene species confined, according to Wood, to Walton and Bentley.

The Little Oakley outlier probably extends over the highest part of that parish, and thence, though not continuously, along the ridge which runs towards Dovercourt Cliff, as shown on the map (fig. 1, p. 710). I was informed by an old man, resident there at the time, that coprolites were formerly dug at the spots marked 6 & 7. I noticed Crag in hedges near South Hall, at 8 & 9, and in a pit ½ mile from Dovercourt at 10: too comminuted at the last-named, however, to yield any good results, but I ascertained by boring that the deposit is 10 feet thick, resting upon the London Clay. I found Crag also by boring at several spots between No. 10 and the cliff; in the garden adjoining the Hotel, however, and as far as can be seen along the cliff, the London Clay comes to the surface.

The small outlier formerly exposed at Harwich, near the spot marked 11 on the map (fig. 1, p. 710), now quite destroyed, seems, so far as the evidence goes, to have belonged to the Waltonian division. The figures drawn by Dale, the Father of Crag geologists,[3] are not all satisfactory, but the following species may be identified from them with more or less certainty:—

[1] M. Van den Broeck mentions a similar shell under the name of *Chrysodomus despecta* var. *carinata*, Sars, Bull. Soc. Belge Géol. vol. vi (1892) Mém. p. 131 (*Neptunea antiqua* var. *tricarinata*, Nyst, 'Conchyl. Terr. Tert. Belg.' Ann. Mus. Roy. Hist. Nat. vol. iii, pt. i, 1881), as characteristic of the Poederlian, an upper zone of the Scaldisian.

[2] Figured in Proc. Internat. Congr. Zool. Cambridge (1898) pl. iii, fig. 8.

[3] 'Hist. & Antiq. Harwich & Dovercourt' London, 1730.

Voluta Lamberti.
Nassa reticosa var. *costata.*
—— —— var. *elongata.*
Buccinopsis Dalei.
Buccinum undatum.
Purpura lapillus var. *intermedia* (the Oakley form).
Trophon costifer.
—— (*Neptunea*) *antiquus.*
—— *despectus.*
—— *contrarius.*
—— (*Sipho*) *gracilis.*
Cerithium tricinctum.
Natica catenoides.
Ostrea edulis.
Pectunculus glycimeris.
Pecten opercularis.
Cardita senilis.
Cardium edule var. *edulinum.*
—— *decorticatum.*
—— *Parkinsoni.*
Astarte obliquata.
—— 2 spp.
Cyprina islandica.
Tellina crassa.
Mactra arcuata.
—— *obtruncata (?).*
Pholas cylindracea.
Terebratula grandis.

These are all common Waltonian species. No small forms are figured by Dale, and it is strange that *Purpura tetragona* and *Artemis lentiformis*, so abundant at other localities in Essex, should not have been observed. On the other hand, had the Harwich Crag been of the same age as that of Felixstowe in Suffolk, on the opposite bank of the estuary of the Stour, forms so characteristic of the latter as the existing variety of *Purpura lapillus*, and *Tellina obliqua*, could hardly have escaped notice. We may therefore, perhaps, include the Harwich bed in the Waltonian division, and take the River Stour as the northern limit of those deposits.

It is possible that Crag may be present beneath the Middle Glacial gravel between Wrabness and Ramsey, though there is no direct evidence that such is the case. I was, however, unable to trace it between Little Oakley and Beaumont. South of the former locality it has evidently been much denuded.

The age of the patch of Crag at Wrabness (No. 12 in fig. 1, p. 710) mapped by S. V. Wood, Jun. during his survey of Essex, and mentioned by Mr. Whitaker in his Survey Memoir,[1] cannot be determined, as no list of fossils from that place is in existence.

I propose to bring before the Geological Society at an early opportunity a complete list of the mollusca etc. from the Waltonian Crag, together with a description of some new species.

III. The Relation of the Waltonian Beds to other Horizons of the Red Crag and to the Norwich Crag.

While, therefore, we may group the Beaumont, Oakley, and Harwich deposits with those of Walton, notwithstanding the slight differences between them, we find on crossing the estuary of the Stour into Suffolk, that the fauna of the Crag-beds there exposed differs from them in important particulars.

At Felixstowe, for example, only 3 miles north-east of Harwich, a number of species, extinct or southern, which are very characteristic of the Essex Crag, are more or less rare, as, for example,

[1] Mem. Geol. Surv. (1877) 'Walton-Naze & Harwich' p. 14.

Columbella sulcata, *Nassa elegans*, *Natica catenoides*, *Trochus Adansoni*, and *Nucula lævigata*; *Cardium Parkinsoni* and *Mactra arcuata* are present, but are not so strikingly abundant as they are in Essex. On the other hand, *Cardium angustatum*, a distinctive form of the Suffolk Crag, exceedingly rare in the Waltonian beds, is very common at Felixstowe, as are *Mactra ovalis* and *M. constricta*, unknown from Walton. The *Tellinæ* (*T. obliqua* and *T. prætenuis*) form at Felixstowe a distinguishing feature of the Crag, although they do not occur in such extraordinary profusion as in beds farther north; *Artemis lentiformis* is comparatively rare, and is not often found perfect. *Nucula Cobboldiæ*,[1] so characteristic of the later horizons, begins there to make its appearance, with an occasional specimen of *Leda oblongoides*. The existing variety of *Purpura lapillus* is abundant, and *P. tetragona* comparatively less so. *Neptunea antiqua* (dextral) is fairly common, though its sinistral representative still outnumbers it, perhaps by 6 to 1. I do not think that any one going direct from Little Oakley to Felixstowe could fail to recognize the difference between the two deposits.

The Felixstowe Crag closely resembles that of Waldringfield and the country lying between the Rivers Orwell and Deben, on the one hand, and that of Sutton, Ramsholt, and Shottisham, west of the Deben, on the other, with which, therefore, as proposed by Wood, it may be grouped, although the list of species recorded from Waldringfield, Foxhall, and Sutton, seems of a slightly older character than that from Felixstowe. For this division I propose the term Newbournian,[2] from Newbourn, the well-known Crag locality, where the 20-foot section, $\frac{1}{2}$ mile north-east of the church, shows obliquely-bedded shelly sand, much of it dipping south-south-westward.

Among other boreal species characteristic of the later horizons of the Red Crag, which are more abundant at this zone than at Walton, may be mentioned *Scalaria grœnlandica*, *Admete viridula*, *Modiola modiolus*, and *Astarte compressa*; *Littorina littorea* appears at this stage for the first time, as does the northern form *Natica helicoides*.

The only exposures of the sheet of Crag which, overlain by Glacial deposits, appears to cover the country between the Stour and the Orwell, that have received any attention from collectors, are at Bentley and Tattingstone; but the fauna contained in them has not at present been worked out, and the exact horizon to which they should be referred cannot therefore be finally determined. S. V. Wood believed, however, that the Bentley deposit, while newer than that of Walton, was older than any other part of the Suffolk Crag.

The Crag of Butley, containing a still larger number of northern, with a smaller proportion of southern species, must, I think, be

[1] I found no trace of this shell during my many visits to Beaumont and Little Oakley.

[2] I prefer Newbournian as a name to Suttonian, for Sutton is also a well-known Coralline Crag locality.

regarded as belonging to a period distinctly later than the rest of the Red Crag.

Neptunea antiqua (dextral) is at Butley nearly as abundant as *N. contraria*. Several species of *Leda* are there met with not unfrequently, and *Nucula Cobboldiæ* is very common; while *Tellina obliqua*, *T. prætenuis*, *Mactra ovalis*, *M. constricta*, and *Cardium angustatum*, with some recent British species, are so abundant as to make up a large proportion of the total number of specimens present. The following northern shells may be noted as more abundant in the Butley zone than in beds of an earlier age, namely: *Trophon altus*, *Buccinum grœnlandicum*, *Natica grœnlandica*, and *Cardium grœnlandicum*. At the same time the proportion of extinct and southern shells is considerably smaller at Butley than in the Newbournian Crag.

There are other exposures of Crag at Alderton, Hollesley, and Bawdsey, containing a fauna similar to that of Butley, the arctic shell, *Cardium grœnlandicum*, very rare in the Newbournian deposits, being especially characteristic of the last-named locality; and for these, with the Crag of Sudbourn and Iken, and of the stack-yard pit at Chillesford,[1] I propose the name Butleyan. This division has a more recent as well as a more boreal fauna than that of the horizons before mentioned.

The distinction between the Butleyan and the Newbournian zones seems to me to be more marked than that between any of the other divisions of the Red Crag (see analysis of molluscan fauna, p. 725).

For the deposits hitherto known as Norwich Crag (an horizon of greater thickness and importance than was formerly supposed), which extend more or less continuously from Aldeburgh in Suffolk to Horstead and Burgh in Norfolk, a distance of more than 40 miles in one direction, and 20 miles, from Hoxne to Southwold, in another, I adopt the name Icenian, originally proposed for the Crag-formation generally by S. P. Woodward.[2] These beds, in places nearly 200 feet thick, occupy an entirely different area from that of the Red Crag, and contain a fauna which differs more widely from that of the latter, than the various divisions now proposed for it do one from the other.

A number of the characteristic shells, extinct and southern, of the older Crag had lingered on in the North Sea, though in gradually diminishing numbers, until the Butleyan Period, of which the following may be mentioned (but they apparently became extinct in the Crag basin before the Icenian Period, killed off possibly by the rapidly increasing cold):—

[1] I am now disposed to think, for the reasons given on p. 734, that the highest bed at this pit, containing *Scrobicularia piperata*, formerly regarded by S. V. Wood, Jun. and myself as representing the Norwich zone, belongs to the newest part of the Butleyan division.

[2] Norwich is supposed to stand on the site of the ancient *Venta Icenorum*.

Ovula spelta.
Cypræa avellana.
Columbella sulcata.
**Cassidaria bicatenata.*
Nassa labiosa.
—— *elegans.*
**Purpura tetragona.*
Trophon costifer.
—— *muricatus.*
—— *elegans.*
Pleurotoma Bertrandi.
Vermetus intortus.
Trochus subexcavatus.
—— *cineroides.*
Dentalium dentalis.
Mytilus hesperianus.
Nucula lævigata.
Cardium Parkinsoni.
—— *decorticatum.*
Astarte obliquata.
—— *Galeotii.*
—— *Basterotii.*
*—— *Omalii.*
*—— *Burtinii.*
Woodia digitaria.
Cyprina rustica.
Gastrana laminosa.
Venus imbricata.
**Cytherea rudis.*
Corbulomya complanata.

The names of those marked with an asterisk may be found in old lists of Norwich Crag shells, but no trace of them has been discovered in late years, and I doubt whether the references are reliable.

In addition to these, some others, which had survived up to the Butleyan Period, and are all more or less characteristic of the Butley zone, are exceedingly rare in the Icenian Beds, namely:—

Nassa reticosa.
—— *granulata.*
—— *propinqua.*
Neptunea contraria.
Pleurotoma mitrula.
Natica hemiclausa.
—— *catenoides.*
Natica millepunctata.
Cardita corbis.
—— *scalaris.*
—— *senilis.*
Cardium interruptum.
Mactra arcuata.

Among the northern species recorded from the Norwich Crag which are unknown in the Red Crag may be mentioned *Trophon Gunneri*, *Tr. berniciensis*, *Velutina undata*, *Margarita grœnlandica*, *Rhynchonella psittacea*,[1] *Leda pernula*, *Astarte elliptica*, and *A. borealis*, only the last-named, however, being abundant. While *Neptunea contraria* is very rare in this zone, *N. antiqua* (dextral) is one of its common shells.

The comparatively modern, as well as more boreal, character of the Icenian Crag is further shown by its meagre fauna of not more than 150 species in all: many of them being excessively rare, and most of the more abundant of them typical British forms.[2] Not more than about 40 are really common, and of such only 5 or 6 are not known living, the latter being characteristic of the higher rather than of the lower zones of the Crag; 2 only are southern, and 9 northern. If the list of marine mollusca (70 in all) obtained by Mr. James Reeve from one of the richest of the Icenian localities (Bramerton, near Norwich),[3] the result of many years' work, be compared with those from the Red Crag of Little Oakley or Butley, the distinction between the Red and Norwich Crags will be, I think, apparent.

[1] Mr. Alfred Bell is said to have found this species at one locality in the Red Crag.

[2] The molluscan fauna of southern seas contains a greater number of species than that of those to the north, that of the Mediterranean being richer than the fauna of British seas, and the latter than those of the arctic regions.

[3] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 457.

The commonest species of the Icenian zone are the following, nearly three-fourths of them being recent, and nearly two-thirds common North Sea forms :—

Buccinum undatum.	*Cardium edule.*
Purpura lapillus.	*Astarte borealis.*
Neptunea antiqua.	—— *compressa.*
Cerithium tricinctum.	*Cyprina islandica.*
Turritella incrassata.	*Tellina lata.*
—— *terebra.*	—— *obliqua.*
Littorina littorea.	—— *prætenuis.*
Natica catena.	*Mactra ovalis.*
Pecten opercularis.	—— *subtruncata.*
Nucula Cobboldiæ.	*Mya arenaria.*
Leda oblongoides.	—— *truncata.*
Lucina borealis.	

The presence at some localities in the Icenian area of a few land and freshwater shells,[1] and of the estuarine species *Scrobicularia piperata*, has been thought to point to estuarine conditions in East Anglia during this period. The widespread area, however, which these deposits cover and their great thickness in places, seem opposed to such a view; and notwithstanding that the general facies of the fauna is more or less of an estuarine character, I am inclined to think that these beds are marine, though accumulated near the mouth of a river, possibly some tributary of the Rhine.

While the Icenian Crag thus covers a larger district than the Red Crag, and is in places of such great thickness, its character is similar throughout, the only palæontological difference of any importance by which the several beds can be divided being that the arctic species *Astarte borealis* is distinctive of the northern part of the area, for it is common near Norwich and in the Bure Valley, less so in the north of Suffolk, while it is unknown farther south, as at Aldeburgh, Bulchamp, Southwold, and Dunwich. *Tellina lata* (*calcarea*) and some other northern forms are also rather more abundant in the northern than in the southern part of the Icenian area.[2]

The estuarine Chillesford Clay and underlying sand, always highly micaceous, the latter containing at the pit behind Chillesford Church a marine fauna still more boreal than that of the Icenian deposits, which indicate a still farther northward retreat of the Crag sea and an emergence of the East Anglian area, may be distinguished by the term Chillesfordian. The most characteristic fossils at the Chillesford Church pit are :—

Turritella terebra.	*Cardium edule.*
Natica catena.	—— *grœnlandicum.*
Leda oblongoides.	*Mactra ovalis.*
—— *lanceolata.*	*Tellina lata.*
Nucula Cobboldiæ.	—— *obliqua.*
—— *tenuis.*	*Mya truncata.*

[1] Hence the former name of Fluvio-marine Crag for these beds.

[2] The upper bed at Bramerton has been generally reckoned much newer than the lower one. There is, however, little difference between the two, except that *Leda oblongoides, Astarte borealis* and *A. compressa* are somewhat more common, and land and freshwater shells less so in the upper than in the lower bed.

A large proportion of the bivalves occur with both valves adherent, but not specially in the position of growth. The deposit does not represent, in my opinion, an undisturbed sea-bottom. The shells present all the appearance of having been drifted; they may have been brought up by the scour of the estuarine tides, and buried while living, or soon after death, in the tidal sediment.

The fossils of the Chillesford Church pit are in a decayed condition, resembling those found in freshwater strata, and contrast strongly with the much better preserved shells of the marine portion of the Crag. This is in harmony with the theory of the estuarine (brackish water) origin of the Chillesfordian deposits.[1] When examined under the microscope, the grains of sand composing the matrix in which these fossils occur are seen to be less rounded than those of the beach-sands of the Red Crag. No glauconite occurs in the Chillesford Sand, and grains of flint are rare in it (see Mr. Lomas's Report, p. 743). In his opinion the material which composes this deposit may have come from a distant source.

For the latest of the Crag-deposits of East Anglia, that of Weybourn and Belaugh, I have proposed the name Weybournian.

These beds, which are characterized by the appearance for the first time in the Crag basin of the recent species, *Tellina balthica* (in the most extraordinary profusion), owing possibly to the opening up of communication with some area,[2] perhaps the southern part of the Baltic, where it had previously established itself abundantly, contain the poorest, as well as the most recent and northern fauna of any of the different horizons of the Crag.

In my paper on the Pliocene deposits of Holland,[3] I suggested that the pebbly gravels grouped by Searles V. Wood, Jun. and myself as the 'Bure Valley Beds' might possibly include deposits of different ages. I now confine the term Weybournian to those only of them in which, on the Cromer coast, and at Belaugh, Crostwick, Rackheath, and Wroxham, *Tellina balthica* is found; and perhaps to the upper part of the Crag-beds near Norwich, regarding the unfossiliferous gravels associated with the Glacial beds in Norfolk, together with the shingle of Westleton, Dunwich, and Halesworth in Suffolk, as distinct (as stated by Prestwich), and probably as Pleistocene.[4]

The mutual relationship of the different deposits is summarized in the following synoptical analysis:—

[1] In his 'Report on the Marine Zoology of Strangford Lough' Rep. Brit. Assoc. (Dublin 1857) p. 110, Prof. G. Dickie noted a similar difference in the condition of the shells dredged within the Lough (an extensive sheet of water communicating with the Irish Sea by an exceedingly narrow channel), and of those met with in the open sea outside it.

[2] See also H. B. Woodward, Mem. Geol. Surv. (1881) 'Norwich' p. 37. The occurrence of a number of characteristic Red Crag shells (although derivative) in gravel-beds on the Aberdeenshire coast tends to show that in the first instance the Red Crag basin communicated with northern seas in that direction.

[3] Quart. Journ. Geol. Soc. vol. lii (1896) pp. 772–73.

[4] The separation between Pleistocene and Pliocene in East Anglia is, however, purely conventional, and must not be taken to indicate any important break in the continuity of these deposits.

ANALYSIS OF THE MOLLUSCAN FAUNA OF THE DIFFERENT HORIZONS OF THE CRAG. (CHARACTERISTIC AND ABUNDANT SPECIES ONLY.)

	Not known living. per cent.	*Living only in distant seas.* per cent.	*Southern.* per cent.	*Northern.* per cent.	*Northern and Southern.* per cent.
Gedgravian......	38	4	26	1	3
Waltonian	36	4	20	5	35
Newbournian...	32	5	16	11	36
Butleyan.........	13	4	13	23	47
Icenian	11	—	7	32	50
Weybournian.[1]	11	—	—	33	56

In calculating the various percentages, the more characteristic species of each zone only are taken into account. It is not always easy to draw the line between rare and abundant forms, and possibly the details which might be tabulated by another observer would be somewhat different. I have little doubt however that, in any case, the general results would agree with those here given, and that the foregoing statistics, though they must be regarded as approximate only, justify the conclusions to be drawn from them.

The so-called Forest-bed Series of the Cromer and Kessingland coasts, shown by Mr. Clement Reid to consist of alternations of fresh-water and estuarine strata, may be known as Cromerian.[2] These beds are equally distinguished by the southern character of their fauna from the underlying Weybourn Crag with its boreal mollusca, on the one hand; and from the *Leda-myalis* Sands, and the Arctic Freshwater Bed with *Salix polaris* and *Betula nana*, on the other. These three groups of deposits indicate a distinct change in climatal conditions—an interruption, for the time, of the gradual refrigeration of the Crag Period, similar to that of the Interglacial episodes of the Glacial Epoch.[3] In the case of the Forest-bed, as in that of the Crag, it is necessary to count specimens rather than species. Northern forms are very rare at the former horizon, *Gulo* and *Ovibos*, for instance, being known from unique examples only, while the remains of Southern mammals, such as *Elephas meridionalis*, are exceedingly common.[4]

These Forest-bed fossils, always fragmentary, occurring either in estuarine or fluviatile mud, and flood-gravel, although they do not necessarily represent the mammalian fauna of Norfolk at the period in question, but rather that of the Rhine Valley to the south, still show clearly, I think, that the climate of North-western Europe was

[1] The above figures do not adequately represent the modern character of the Weybournian fauna. If individuals could be counted rather than species, the recent shells would form more than nine-tenths of the whole: the specimens of *Tellina balthica* alone far outnumbering all the others put together.

[2] See Renevier's 'Chronogr. géol.' 2nd ed. (1896) of his 'Tableau des Terrains sédimentaires.'

[3] Prof. James Geikie believes that the Weybourn Crag represents the lowest Boulder Clay of Southern Sweden: see his 'Great Ice Age' 3rd ed. (1894) p. 479, also pp. 336 *et seqq.*

[4] I did not give, in my paper on the 'Pliocene Deposits of Holland' Quart. Journ. Geol. Soc. vol. lii (1896) p. 774, such weight to these considerations as I now think they deserve.

not then arctic.[1] Moreover, the Forest-bed flora, as Mr. Reid has told us, was similar to that of Norfolk at the present day.[2]

On the contrary, the *Leda-myalis* Sands, which contain also *Astarte borealis*, seem naturally to group themselves with the Arctic Freshwater Bed, as belonging to the same epoch and originating under similar climatal conditions. Both should be regarded, I think, as Glacial, rather than as Pliocene.[3]

IV. The Derivative Mollusca of the Red Crag.

Whether or no any considerable proportion of the Red Crag mollusca have been derived from older formations, is a question upon which much difference of opinion has existed. Both Searles V. Wood [4] and his son,[5] as well as Prestwich, believed that many Red Crag shells were extraneous (the lists of such forms given by them having, however, little in common); Prestwich, indeed, expressed the extreme opinion that all species which occur in the Red but not in the Norwich Crag are so.[6]

While a few forms characteristic of horizons older than the Coralline Crag may be derivative, possibly from submarine shell-banks of Older Pliocene age then existing in the Red Crag sea, I do not now think that the Red Crag fauna has been leavened with an admixture of Coralline Crag species. There are Miocene shells which still live in the North Sea, and it seems more probable that some Coralline Crag mollusca may have lingered on there until Red Crag times, than that any specimens should have been washed out of the former deposit into the latter. We have no positive evidence, moreover, that such has been the case. It is not at Tattingstone, Ramsholt, or Sudbourn, where the Red Crag rests upon, or against the Coralline Crag, or at the stack-yard pit near Shottisham Creek, where fragments of indurated Coralline Crag are embedded in the former, that such specimens are so frequently met with, as in the

[1] During the Weybournian Period there may very probably have been considerable accumulation of snow and ice on the Swiss highlands, the melting of which, when the climate became milder, would produce, especially in spring, sudden and violent floods. Animals frequenting the low pasture-grounds bordering the Forest-bed river and its tributaries would thus be annually caught and swept away. In this manner only can we explain, I think, the presence, in so limited an area, of such enormous quantities of mammalian remains. It may be worth noticing that they seem to occur in beds deposited on the convex side of one of the great bends of the Forest-bed estuary, that is, from Kessingland in Suffolk to Cromer (they are not found, so far as we know, at any great distance inland), where the heaping-up of sediment and wreckage would naturally take place.

[2] Mem. Geol. Surv. (1890) 'Plioc. Beds of Britain' p. 185.

[3] Mr. Reid seems inclined to separate the *Leda-myalis* Sands from the Arctic Freshwater Bed, regarding the one as Pliocene and the other as Pleistocene. The introduction of the latter term was, I have always considered, a mistake. It is not, however, so objectionable as Quaternary.

[4] Quart. Journ. Geol. Soc. vol. xv (1859) p. 32.

[5] '3rd Suppl. Monogr. Crag Mollusca' Pal. Soc. (1882) p. 19.

[6] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 350. Prestwich evidently felt that this argument cuts both ways, and he consequently regarded all Red Crag forms which occur also at any other later horizon, as in what were then called the Sables jaunes of Belgium, or in the Glacial beds, as being proper to the Red Crag, and not derivative.

nodule-bed at Waldringfield and elsewhere, at some distance from any known exposure of the older deposit. Shells from the Coralline Crag are not coated with silicate, as are those from older Tertiary formations, and being composed, as a rule, of pure carbonate of lime, are more or less fragile, so that some of them can only be extracted in perfect condition with the most elaborate care and great difficulty. It is not easy to understand that such fossils could have survived the rough treatment to which, on the derivative hypothesis, they must have been exposed in the shallow Red Crag sea, whose waves reduced a great part of the shells of molluscs then living in it to a mass of indistinguishable fragments.[1] Many of the species formerly looked upon as derivative from the Coralline Crag have been obtained in recent years from the Scaldisian of Belgium,[2] and the still later Amstelian deposits of Holland; and, moreover, we find that in the Norwich Crag, where the idea of derivation is not suggested, some characteristic Coralline Crag forms occur occasionally, in certain localities only.

In the Third Supplement to the Monograph of the Crag Mollusca, published in 1882 (after his father's death), S. V. Wood, Jun. maintained, when dealing with the Crag of Felixstowe (Newbournian), that a considerable number of the species found at that place, including such forms as *Cypræa avellana*, *Voluta Lamberti*, *Nassa reticosa*, *Purpura tetragona*, *Trophon costifer*, *Pectunculus subobliquus*, and *Artemis lentiformis*, had been derived from the destruction of earlier Red Crag beds (Waltonian) formerly occupying the Newbournian area.[3] I am compelled now to differ from my old friend, though with great regret. The Red Crag deposits, I believe, were strictly littoral, and as the sea was gradually retiring northward, it was rather leaving behind it beds which it had accumulated at an earlier stage, than eroding them.[4] If the shells mentioned above had ceased to exist during the later part of the Red Crag Period, they ought to have been deposited at the base only of the different exposures of the more recent zones: that is, when the sea was (*ex hypothesi*), as it began to occupy a new area, destroying and reconstructing any earlier shell-banks that may have existed there; but this is not the case, so far as I know.

The species just named, supposed by Wood to be Waltonian only, occur, moreover, in every part of the Red Crag, and at localities like Butley, the fauna of which has not been generally thought to contain derivative shells.[5]

[1] The rolled and worn condition of some of the specimens supposed to have been derived from the Coralline Crag appears to me an argument against, rather than for, their extraneous origin.

[2] 41 out of the 104 species regarded by Wood as derivative, and 27 out of the 46 given by Prestwich as such, occur in the Belgian or Dutch beds. Of the rest, I have found about 30 at Little Oakley or Beaumont.

[3] S. V. Wood, Jun. and I had suggested a similar view in 1872, '1st Suppl. Crag Moll.' Monogr. Pal. Soc. p. vii.

[4] It must be admitted, however, that the Red Crag south of the Stour has been much denuded.

[5] It is, of course, possible that, in the constant rearrangement by the waves of the shelly material composing the beaches of the Red Crag sea, some specimens may have found their way from the Waltonian to the Newbournian,

V. The probable Conditions under which the Red Crag Deposits originated.

The Coralline Crag deposits are of two kinds: first, the shelly sands, principally organic, the subject of my former paper, originating as submarine banks in water of a moderate depth; and next, coarse rolled material, containing mammalian and other derivative fossils, the littoral drift of that period, accumulated as the basement-bed of the formation, at a time when strong currents from the south or south-west were entering the Crag basin, and the beach was consequently travelling from south to north.[1] The latter deposits, known *in situ* at Sutton only, where they occur at the base of the Coralline Crag, represent the earliest invasion of East Anglia by the Pliocene Sea. As submergence proceeded, and these basement-beds were covered in places by shelly sands, the shore-line was carried somewhat to the west, where accumulation of littoral débris still went on, contemporaneously with that of the former, farther from the coast.

At the close of the Gedgravian (Coralline Crag) Period, an upheaval of the southern part of the Crag area took place, causing some denudation, apparently greatest towards the south, as the outliers of Coralline Crag in that direction, at Tattingstone, Ramsholt, and Sutton, are small and probably fragmentary. This denudation destroyed any of the shelly sands (with the exception of these outliers) that may have existed in that part of the Crag district; but the boxstones and other débris associated with them, better able to stand the wear-and-tear of the advancing sea, were preserved, and went to form the basement-bed of the succeeding Red Crag.[2] That the sources from which they were obtained were cut off before the Red Crag Period (possibly by the southern elevation which destroyed the communication between the North Sea and the English Channel, and interrupted the tidal currents from the south till then existing) is shown by the fact that no such littoral material is found in the Red Crag, except towards the base of the formation. If we adopt the view that the mammalian remains contained in these basement-beds, equally with the mollusca of the boxstones with which in Suffolk they are found, are derivative,[3] that they were brought into the Crag area by currents, or by the travel of the beach, at the commencement of the Gedgravian Period, having been derived principally from Pliocene strata older than the Coralline Crag formerly existing to the south,[4] and that the nodule-beds originally

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or from the Newbournian to the Butleyan district. The subject is perhaps one upon which there is room for a difference in opinion; on the whole, however, I believe that the lists of shells from the various Red Crag localities correctly represent the molluscan fauna of each zone.

[1] Quart. Journ. Geol. Soc. vol. liv (1898) p. 315.

[2] See also H. B. Woodward, 'Geol. Engl. & Wales' (1876) p. 285.

[3] We could hardly expect them to occur so abundantly in a marine deposit, if they were not derivative: the remains of land-mammalia are not usually found under such conditions.

[4] Mr. P. F. Kendall and I found in September 1899, on the beach at Folkestone, fragments of indurated ferruginous sandstone, of composition similar to that of the boxstones, which had fallen down from beds of Lenham (Diestian) age at the summit of the cliff.

containing them were subsequently reconstructed, it removes the difficulty of supposing that animals of an older and southern type, such as *Mastodon*, lived in this country, not only during the Coralline and Red Crag Periods, but during that of the Norwich Crag also, co-existing with the comparatively modern molluscan fauna of the latter, and with arctic shells like *Astarte borealis*, *Cardium grœnlandicum*, and *Tellina lata*. On the other hand, no remains of this pachyderm have been found in the closely connected estuarine (Forest-bed) deposits of the Cromer coast, although the great river to which these were due drained an area far south of Great Britain.[1] There is indeed no more evidence for the existence of *Mastodon* in England during any part of the Crag era, than for that of *Hipparion*, or of the Eocene *Hyracotherium*, the fossil remains of which are found with it in the nodule-beds.[2]

[1] Prestwich believed that most of the mammalian remains which occur in the Red Crag are derivative, 'Geology' vol. ii (1888) p. 422.

[2] The theory of the existence of *Mastodon* in England during the Icenian (Norwich Crag) Period rests principally on the alleged discovery of the entire skeleton of that animal at Horstead, Norfolk, in 1820; see H. B. Woodward, Mem. Geol. Surv. (1881) 'Norwich' p. 57.

Nearly forty years ago I visited Horstead with my friend the Rev. John Gunn, for the purpose of investigating the matter on the spot, and came away with a strong opinion that the evidence in its favour was of the most unsatisfactory character. All that could be proved was that a number of bones had been found on the surface of the Chalk, which (we were told) were taken away on a cart; but they were not submitted to the examination of any competent observer. Some time after, a single tooth, said to have been that of *Mastodon*, and to have been obtained at the same time, found its way, at second hand, into the possession of the Rev. James Layton of Catfield, a village 8 miles from Horstead, and upon this one specimen, and some subsequent hearsay statemen s of the workmen, the story of the supposed discovery has been founded. A railway-truck, however, rather than a cart would have been required to remove the skeleton of such an animal, or any considerable part of it. At that time excavations were being made at right angles to the River Bure, and extending some way back from it, of the size and form of a deep railway-cutting, to enable barges to pass from the river to obtain chalk. There was no cart-road by the side of these canals, so far as I remember, but only a small footpath. Sections of Chalk, covered by thick beds of Crag sand, were exposed in this way' the quarrymen removing a few feet of the latter at a time, so as to uncover a narrow shelf of the Chalk just sufficient for them to work on. Had the skeleton of a great pachyderm been present, 'lying on its side' as stated, it would have taken many months to have got it out, as the cuttings were carried back but slowly, and the Vicar of Catfield would have had every opportunity of seeing some part of it *in situ*. It seems clear that when he visited Horstead, which he says he did 'at the first opportunity,' all traces of the alleged discovery had been removed. It is perhaps worthy of notice that no mention is made of the finding of tusks, which, even if decayed, would certainly have attracted attention, or of more than one tooth. No skeleton of any vertebrate, or even a portion of one, has ever been recorded from the Norwich Crag, the mammalian remains met with in that deposit being fragmentary, and, as a rule, worn. Specimens of the teeth of *Mastodon* have occurred at other places at the base of the Norwich, as of the Red and Coralline Crags, and the Horstead case has, I submit, neither more nor less evidential value than the rest. The want of correspondence between the terrestrial mammalian fauna of the Forest-bed and that of the stone-bed at the base of the Norwich Crag, is, I think, worthy of notice. Out of more than 40 species enumerated in Mr. E. T. Newton's list from the former (excluding doubtful identifications) and 12 from the latter, only 4 are common to both.

The marked difference between the shelly marl of the Coralline Crag, containing only about 12 per cent. of exceedingly fine inorganic material, and the much coarser quartzose sands of the Red Crag, points to some change in the geographical conditions of the Crag basin. In the Coralline Crag, we have the spoil of the sea-bottom, principally organic: shells and shell-fragments heaped up in submarine banks by currents; in that of the Red Crag, there is, in addition to shelly débris, a large percentage of inorganic material derived from coast-erosion, and sediment brought down by rivers, which afterwards accumulated against, or near to the shore.

In a paper which I have quoted on a former occasion,[1] Mr. W. H. Wheeler gives his reasons for believing that in our shallow seas at the present day very little permanent movement of sand derived from coast-waste takes place below low-water mark, the coarser part of such material only being carried along the shore by tidal action, and, further, that the supply of such littoral drift is exceedingly limited. If this be so now, when many parts of the English littoral are fringed by cliffs of Glacial sand and sandy clay, still more must it have been so in East Anglia during the Later Pliocene Period, when strata of Eocene clay formed the margin of the Red Crag sea. It does not, therefore, seem probable that the waste of the land by wave-action could, of itself, have supplied material for the inorganic portion of the enormous mass of sandy Crag which covers so much of Suffolk and Norfolk. There is no evidence that any river entered the English Crag area during the deposition of the Gedgravian Beds, but the contrary may have been the case during the Red Crag Period.

My friend Mr. Joseph Lomas, F.G.S., to whose researches, with those of Prof. Herdman and his colleagues of the Liverpool Biological Society, on the 'Floor-deposits of the Irish Sea,' students of the Crag owe so much, has very kindly undertaken the microscopical and chemical examination of material taken from different parts of the Red Crag and Norwich Crag areas, a task involving much labour and skill, for which, and for the Report appended to this paper (p. 738), my best thanks are due. His researches, showing that the sandy material of the different zones of the Red Crag, and to a great extent that of the Norwich Crag also, is identical in composition throughout, except that the latter contains more mica, as was previously known, tends to establish the generalization that all these beds were deposited generally (except as explained on p. 735) under similar geographical conditions.

It is interesting to notice that many of the minerals which Mr. Lomas has found in the Crag sands, such as garnet, rutile, zircon, tourmaline, ilmenite, and others, are common in the Tertiary deposits of Belgium,[2] having been derived, according to M. Rutot, from Cambrian rocks in the Ardennes, in which, he says, garnets in small crystals are especially abundant.

[1] 'Littoral Drift: in its Relation to the Outfalls of Rivers, &c.' Proc. Inst. Civ. Eng. vol. cxxv (1896) pp. 2–32.

[2] The occurrence of these minerals is, however, very widespread.

The Red Crag deposits rest against, rather than upon, the Coralline Crag. At Sutton, the well-known case of a bed of *Mytili* in place, with adherent valves, indicates, in Prestwich's opinion, an old shore-line.[1] Both the small outlier of Coralline Crag at Sutton, to which near tide-marks this colony of mollusca attached themselves, and the larger one extending from Gedgrave to Aldeburgh, which does not appear to have been submerged by the Red Crag sea, must have formed, at that time, islands in it. We have therefore a datum-line, more than 12 miles long from south-west to north-east, by which we may fix, with some approach to accuracy, the depth of the shallow water in which the Red Crag originated.[2] Messrs. A. & R. Bell, however, have expressed the opinion that the Red Crag fauna is at some localities, as at Waldringfield, of a deeper-water character than it is at others.[3] If this were so, it would indicate a difference, not in the former depth of the sea at such spots, but in the direction of the currents, or the strength of the wave-action which prevailed there.[4] No instances occur in the Red Crag of an undisturbed sea-bottom, except the unstratified bed at the base of the section at Walton Cliff, and one or two similar cases on a smaller scale. The fossils of the Red Crag are, with these few exceptions, the drifted and stratified shells of dead mollusca, deposited either against the shore, or in shallow water in proximity to it.

At the present day, it is in land-locked or sheltered bays, or within the embouchures of estuaries, that, on the English coast, sandy sediment is mostly accumulating. Along those parts that are exposed to the action of tidal currents, the beach travels, but on the whole it does not increase in extent seaward; sheltered bays, however, act as catchment-areas, arresting its progress, and it is under such circumstances heaped up against the shore by wave-action, or it accumulates in shallow water as banks or shoals.

Where rivers have been discharging in the vicinity, accumulation has naturally gone on to a greater extent, and in proportion to the amount of sediment brought down by them, now, or at some former period: as, for example, on the Lancashire coast in Morecambe Bay, or in the estuaries of the Dee and Ribble; and on the eastern coast of Great Britain, in the Wash, and the estuary of the Thames.

Dead shells often accumulate in such sheltered places, as in Morte Bay on the north-western coast of Devon, where the beach is covered with them; or on Padstow Sands, of which they form

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 340. Mr. P. F. Kendall noticed a similar bed of *Mytili* in the pit at Sudbourn, No. 19 of my former paper, Quart. Journ. Geol. Soc. vol. liv (1898) fig. 4, p. 326, where the Red Crag rests upon the Coralline Crag.

[2] Prestwich observed, moreover, ripple-marks, indicative of a shore from time to time uncovered by the tide, in the Crag at Bawdsey, Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 327 & fig. 7.

[3] Proc. Geol. Assoc. vol. ii (1873) p. 193.

[4] A similar phenomenon may now be observed on our beaches, where the shells of some species are cast up at one spot, and not at another.

90 per cent., being blown up from the sea-bottom by gales of wind.[1]

At present the coast of East Anglia is singularly destitute of drifted shells. Except in the extreme north-western corner of Norfolk, between Hunstanton and Wells, which is exposed to north-westerly winds, one may walk along the beach for many miles and hardly find a specimen. It is evident, therefore, that conditions other than those of the present day must have obtained along the western shore of the North Sea during the Newer Crag Period. When we cross the North Sea to Holland, however, we find dead shells everywhere: along the beach; fringing the shores of estuaries; and accumulating in channels through which tidal currents no longer run. So enormous is the amount of these débris that carts are constantly at work removing them from the beach, and powerful steam-dredgers dredging them from the estuaries,[2] to be burnt for lime. On the flat sandy beaches of the open coast-line, as at the southern extremity of the island of Texel, the shells lie, mixed with sand, in nearly horizontal sheets; while along the shores of estuaries, and against sand-banks, and in channels of former bays now being silted up, the débris (composed of fragmentary as well as of perfect shells) are more or less obliquely-bedded. This accumulation of shelly sand is attributed by Dutch geologists, and I think with reason, to the prevalence of gales from the west. If this be so, it would seem that strong winds from the east, rather than from the west, must have prevailed on the shores of East Anglia during the Newer Crag Period. In a short paper read before Section C of the British Association at Dover, published in abstract only,[3] I gave my reasons, from a meteorological standpoint, for thinking that such was probably the case, and I hope hereafter to be able to deal more fully with the subject. It seems, however, that in the conditions now existing in Holland we have a counterpart of those of East Anglia during the Later Pliocene Epoch, and may thus obtain an explanation of the means by which so enormous a quantity of shelly débris then and there accumulated.

S. V. Wood, Jun. suggested in 1864[4] that the oblique bedding common in the Red Crag indicates that it originated, to a great extent, as a beach-deposit.[5] The frequent south-south-westerly dip of the highly inclined laminæ shows, however, that the Red Crag could not have been wholly accumulated against the southern shore of the North Sea while it was gradually retreating northward. The tectonic movement which affected the Anglo-Belgian basin must, therefore, have taken the form, not so much of a continuous subsidence in one direction, and an upheaval in the other, as of a

[1] Christopher Claxton, Minutes of Evid. in Parl. Report on Harbours of Refuge (1858) p. 98.

[2] About 3,600,000 cubic feet of these shells are dredged yearly, at one spot.

[3] Rep. Brit. Assoc. (1899) p. 753.

[4] Ann. Mag. Nat. Hist. ser. 3, vol. xiii (1864) p. 185.

[5] It is oblique rather than current-bedding that is characteristic of the Red Crag.

succession of foldings which shifted the area of deposition from time to time. In this way, I think, a series of land-locked bays were formed, one after the other, and were successively silted-up by sediment, deposited, partly against the shore, and partly as banks or shoals in the shallow water. Under such circumstances the beds would dip, of course, in different directions on the opposite sides of the bays.[1]

The position which these bays of the Red Crag Period successively occupied may be, I think, approximately defined. A reference to the map (fig. 3, p. 714) will show that the geographical divisions of the Crag, indicated by the differing character of their molluscan fauna, are bounded, broadly speaking, by the estuaries of the Stour, Orwell, and Deben, which radiate from a point slightly east of Harwich: the Waltonian Beds being confined to Essex, south of the Stour; the Newbournian occurring principally between the Orwell and the Deben; and the Butleyan being found only to the east of the latter.

If S. V. Wood's opinion be correct, that the Crag of Bentley (which possibly represents that of the unexplored district between the Stour and the Orwell) is intermediate in age between the Crags of Walton and Newbourn, the whole of the Red Crag divides itself into zones, the geographical limits of which coincide nearly with those of the estuaries named.[2] Thirty-five years ago his son expressed the opinion that the principal valleys of the East of England form more than one series of concentric and inosculating arcs, caused by tectonic disturbances which had their foci in the South of England,[3] and at a later date he returned again to the subject.[4] The Crag district has certainly been subjected to some such folding process, and the coincidences alluded to may possibly hereafter prove worthy of further notice.

Although it appears, from the researches of Mr. Lomas, that there is little difference in composition between the sands of the Red and the Norwich Crags, except that the latter are more micaceous (implying, I think, a closer connection, during their deposition,

[1] Instances of the silting-up of such bays in recent times are by no means uncommon, especially in Holland. There is an area south of the Hoek van Holland, for example, which seems to me to represent exactly the condition of East Anglia during the Red Crag Period. What was formerly a bay or inlet is now nearly choked with shelly sand, which is, however, still accumulating along the shores of the Maas estuary, on the edges of shoals, and in channels formerly occupied by the river, being often bedded at a high angle, dipping of course in different directions as the deposits follow the sinuous winding of the banks. Farther inland, also, are similar beds of shelly sand—the deposits, under similar conditions, of an earlier, though geologically recent period.

[2] The Red Crag sea does not seem to have extended westward beyond the limits of the Eocene beds, so as to reach the Chalk outcrop, or littoral accumulations of chalk-flints would have resulted. Indeed at Sudbury, the westernmost point to which the Crag has been traced, it shows evident signs of thinning out against the old shore-line.

[3] Phil. Mag. ser. 4, vol. xxvii (1864) p. 180.

[4] MS. paper in the Geological Society's Library.

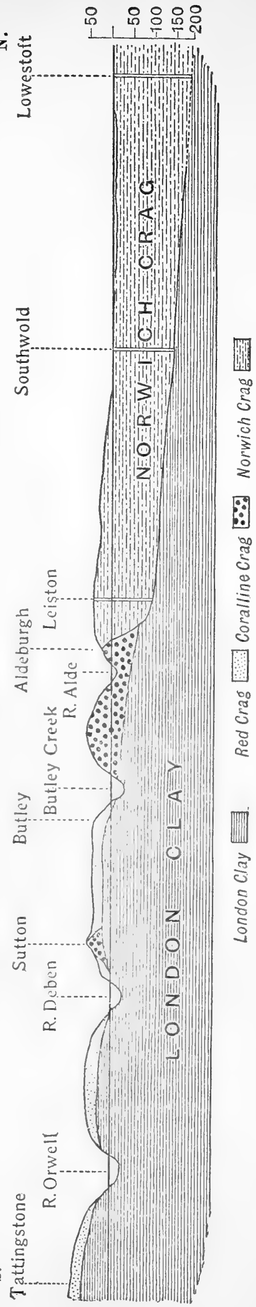


Fig. 5.—*Section from Tattingstone to Lowestoft, showing the comparative thickness of the Red Crag, and of the Norwich Crag of East Suffolk, as also the rapid thickening of the latter northward. (Glacial deposits are omitted.)*

between East Anglia and the Rhine, from rocks in the basin of which the mica was probably derived), it appears that the conditions under which the two formations originated were somewhat different. While the Red Crag was apparently deposited in confined bays or inlets, the Norwich Crag beds occupy a much larger and more exposed area (see map, fig. 3, p. 714). The latter are not so constantly fossiliferous; they are more or less horizontally stratified; and they never present the highly inclined beach-like bedding of the Red Crag. The Red Crag, moreover, where its junction with the London Clay is exposed, as is the case in places from Tattingstone and Walton in the south, to Bawdsey, Ramsholt, and Sutton in the north, does not attain a greater thickness than about 20 or 25 feet. At Butley and Chillesford, farther north, where the base of the Crag dips below the water-line, it may perhaps be somewhat, although not much, thicker. When we pass north of Aldeburgh, however, where the Icenian (Norwich Crag) Beds come on, we find that the Crag thickens very rapidly, attaining 134 feet at Leiston[1]; at Southwold, 9 miles farther north-west, it reaches 140 feet below sea-level, with a total thickness of 147 feet[2]; while in a recent boring at Lowestoft, mentioned by Mr. C. Reid, its base was not reached at 180 feet.[3]

Deposition and subsidence in East Anglia during the Norwich-Crag era seem to have proceeded *pari passu*, as was the case during the Pliocene Period in Holland, although not to so great an extent as in that country. This state of things was due in both, however, to the same cause. The greatest

[1] From information kindly supplied by Mr. W. H. Dalton, F.G.S.
[2] Mem. Geol. Surv. (1887) 'Southwold' p. 79.
[3] Summ. of Progress of Geol. Surv. for 1898 (1899) pp. 145-46.

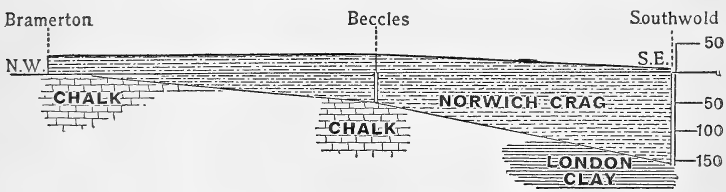
subsidence recorded is that evidenced by the deep borings at Amsterdam, where the base of the Amstelian deposits was not reached at a depth of 1100 feet; and it died out on the south-west, that is, towards the East Anglian margin of the Crag sea.[1]

This movement of the Pliocene sea-bottom in Holland was coincident with, if not caused by, the accumulation of the sediment brought into it by rivers; and as the Dutch deposits represent the ancient delta of the Rhine and its affluents, it seems more than probable that the micaceous sands of the Norwich Crag, although not contemporaneous with the Amstelian strata, also may have had a similar origin: the heaping-up of sand, and of dead shells against the western margin of the Crag sea, being favoured by the prevalence at that time of easterly winds.[2]

I have given my reasons elsewhere for believing that at a somewhat later period the estuary of the Chillesford Clay formed one of the outlets of these rivers,[3] as did afterwards also (as pointed out by Mr. Clement Reid) the estuary of the so-called Forest-bed of the Cromer coast.[4]

The following diagrammatic section, drawn from Bramerton near Norwich to Southwold, shows the increasing thickness and dip of the Icenian Beds in a south-easterly direction, that is, towards Holland.

Fig. 6.—*Section from Bramerton, near Norwich, to Southwold.*



[The Glacial deposits are omitted.]

It should also be noticed that the gradually increasing dip and thickness of the Icenian Beds from south to north is of the same character as that of the Amstelian deposits of Holland, as shown by the deep borings at Utrecht, Amsterdam, and elsewhere.[5]

VI. Summary.

The line separating the Older and the Newer Pliocene deposits of the East of England should be drawn between the Lenham Beds (zone of *Arca diluvii*) and the Coralline Crag, instead of between the latter and the Crag of Walton, as hitherto.

[1] Quart. Journ. Geol. Soc. vol. lii (1896) pp. 753, 761 & figs. 3–4.

[2] Gradual and concurrent subsidence seems to be a common feature of delta-formation in all parts of the world.

[3] Quart. Journ. Geol. Soc. vol. lii (1896) p. 770.

[4] Mem. Geol. Surv. (1882) 'Cromer' p. 57.

[5] Quart. Journ. Geol. Soc. vol. lii (1896) fig. 4, p. 761.

The Upper Crag deposits are not of uniform age, as believed by Prestwich, but arrange themselves in zones, characterized by a gradually diminishing percentage of extinct and southern, and an increasing percentage of recent and northern mollusca.

Although these zones contain faunas sufficiently distinct to justify their separate classification, they all form part of a more or less continuous and closely connected series; they group themselves in horizontal, and not in vertical sequence, the older deposits occurring invariably towards the south of the Crag area, and the newer towards the north.

The term Red Crag is too comprehensive, and, when we attempt to correlate the East Anglian deposits with those of Belgium and Holland, inconvenient. While retaining it for general use, it seems desirable to adopt for its different horizons some more definite and distinctive names. The classification tabulated on p. 708 is therefore proposed.

The Oakley zone is a new horizon of the Crag, intermediate in age between the Walton Bed, with its southern fauna, and the Suffolk Crag in which northern mollusca are more or less common; it represents the period before the southern shells had begun to die out, when a few boreal forms, invading the Anglo-Belgian basin from the north, were establishing themselves in greater or less abundance in the Crag sea.

The earliest indication of the conditions obtaining during the Red Crag Period is afforded by an unstratified bed at the base of the Walton cliff-section, not now visible, originating in comparatively shallow water, where a colony of mollusca lived and died. No trace of this bed has been met with in deposits of Waltonian age in other parts of Essex.

A slight upheaval of Northern Essex afterwards took place, causing the Walton area to form the edge of a land-locked bay, which was gradually silted-up by material, brought down possibly by a river entering the Crag sea at no great distance. To some extent the silting process went on from north-north-east to south-south-west, the shelly sand being obliquely bedded against the northern shore of the Waltonian bay, or deposited in the form of banks or shoals within it (see map, fig. 3, p. 714). A subsequent but slight submergence permitted the deposition of horizontal beds upon the obliquely-bedded Crag,[1] and carried the sea over a gently sloping shore of London Clay to the west towards Beaumont, and afterwards northward to Little Oakley, some erosion of the Eocene beds taking place as the sea encroached upon the land.[2] The bed of pebbly gravel underlain by clay, forming the upper part of the

[1] A similar state of things is to be seen in the stack-yard pit at Chillesford, where horizontally-bedded Crag rests upon beach-Crag, indicating, as at Walton, the gradual subsidence of the beach and the encroachment of a shallow sea over the adjoining land.

[2] The fact that phosphatic nodules are principally found towards the base of the Crag seems to show that it was when the position of the Red Crag sea was shifted, and the sea invaded a fresh area, that denudation of the Eocene strata took place; and that this denudation ceased when the new bay began in its turn to be choked by the deposition in it of shelly sand.

Walton cliff-section (fig. 2, p. 711), with the gravel of Clacton, a few miles to the south, may possibly belong to a subsequent stage of the Crag, when the Walton area had been slightly elevated, and was occupied by the embouchure of the river before referred to, the Crag sea having retreated into Southern Suffolk, destroying as it did so any Older Pliocene beds which may have existed there, except the littoral deposits of the Coralline Crag sea with their derivative fossils, which were reconstructed so as to form the basement-beds of the Newbournian Crag at Waldringfield and elsewhere.

The Newbournian stage is separated from the Waltonian, not only by the time required for the tectonic movement which carried the Crag sea into Suffolk, but for the arrival in the Crag basin of further immigrations of northern mollusca. The Newbournian bay was in its turn silted-up by material lithologically identical with that of the Waltonian Beds. To a great extent the beach- or shoal-deposits of this period grew also from north-north-east to south-south-west,[1] the small outliers of Coralline Crag at Sutton and Ramsholt, and the main mass of that formation from Gedgrave to Aldeburgh, forming at that time rocky islands in the sea.

Disturbance again ensued, but caused a subsidence towards the east, so that a part of the Crag sea shrank into a narrow inlet, extending from Chillesford to Bawdsey, bounded on the east by the great bank of Coralline Crag against which the Butleyan deposits rest. This bank was then more or less of the same extent and form as at present, for Red Crag-beds fringe it on the eastern or seaward side also, at Orford and Sudbourn. A small stream may have entered the Butley inlet from the north, as Mr. Alfred Bell discovered many years ago at that locality a seam containing land and freshwater shells.[2] This bay was in its turn choked with sediment, much of the lower part of it bedded at a high angle, as if against the edge of a steeply sloping shore or shoal, and in places with a south-south-westerly dip, but overlain, as at Walton, by Crag horizontally stratified. If the accumulation of sediment in this part of the Crag area commenced from the north, as seems possible, the beds at Bawdsey, in which *Cardium grœnlandicum* is so abundant, may be the latest of the Red Crag Series, and more recent than those of Sudbourn or Butley. For a similar reason, the Crag of Felixstowe may be somewhat newer than that of Waldringfield, farther inland: a view which, from the study of the molluscan fauna of these two places, seems to be not improbable.

The Norwich Crag-beds (Icenian) are separated by a considerable interval from any part of the Red Crag. Their molluscan fauna has a much more recent character; they never exhibit the highly inclined bedding so characteristic of the Red Crag, and they attain a much greater thickness than the latter; they occupy an entirely different area, and appear to have originated under somewhat different conditions, being possibly the western edge of the great

[1] See as to this also many of the sections in Prestwich's paper, Quart. Journ. Geol. Soc. vol. xxvii (1871) pp. 329 *et seqq.*

[2] Geol. Mag. 1871, p. 452. Such shells occur also at Hollesley, according to Mr. P. F. Kendall.

delta-deposit of the Rhine, which attains such vast proportions in the subsoil of Holland. The subsidence of portions of Holland and of the North-Sea basin, which went on *pari passu* with the accumulation of this delta, seems to have died out towards East Anglia: the Icenian deposits becoming gradually thinner as we trace them southward and westward.

The Weybournian Crag occurring only north of the map (fig. 3, p. 714), divided from the Icenian by the estuarine Chillesford Beds, does not extend into Suffolk, and is probably, as explained on p. 724, distinct from the shingle of Westleton and Dunwich, which may be of Glacial age.

Although a few species of mollusca found in the Red Crag which seem characteristic of an earlier horizon may possibly have been derived from Older Pliocene beds, it does not appear to me that the Red Crag has been leavened by an admixture of Coralline Crag forms. The mollusca of the boxstones which occur in places at the base of both the Coralline and the Red Crags, equally with the Eocene fossils found with them, are, however, derivative in the Crag, as are the remains of *Mastodon*, and other mammals which seem quite out of place in these comparatively recent deposits.

The conditions under which the Newer Crag-beds originated seem to exist at the present day in Holland, where sandy material brought down by rivers into the sea has been thrown against and upon the shore, together with the shells of marine mollusca, and probably by winds from the west. From meteorological considerations it seems possible that strong gales from the east may have prevailed over the Crag area during the latter part of the Pliocene Epoch. This would explain why shelly sand accumulated in such enormous quantities on the East Anglian margin of the North Sea at that period, while at the present day the eastern coasts of Norfolk and Suffolk are almost wholly destitute of such débris.

The so-called Forest-bed, with its southern fauna, indicates a distinct change in climatal conditions, similar to that of the Interglacial episodes of the Pleistocene Epoch, and should be separated, on the one hand, from the Weybourn Crag, and on the other (as urged by Prof. James Geikie[1]) from the *Leda-myalis* Sands and the Arctic Freshwater Bed. The latter two seem naturally to group themselves together, and with the Glacial deposits.

VII. Appendix.

Report *on the* Inorganic Constituents *of the* Crag.

By Joseph Lomas, Esq., A.R.C.S., F.G.S.

Red Crag.

For the purposes of this enquiry the proposed zones of the Red Crag—Waltonian, Newbournian, and Butleyan—may be taken together, as no essential differences in the contained minerals can be detected.

Very marked distinctions in colour are noticeable in different

[1] 'Great Ice Age' 3rd ed. (1894) p. 336, etc.

localities, but these largely depend on varying degrees of impregnation with iron. The iron-staining undoubtedly took place after the beds were deposited, and differences in amount can be traced to the flow of water containing iron in solution. Thus, it is found that where the Crag rests upon a clayey foundation, as at Beaumont, the line of parting has formed a channel along which water has flowed.

In some cases, as is well seen in the pit near Beaumont Hall, the lines of infiltration run across the bedding in wavy lines. It is evident that water percolating through porous rock must trend towards an outflow. When a line of flow has once been established, most of the water will move through certain channels and, carrying iron in solution, there will be a tendency to form pipes by the deposition of iron-oxide in the interstices of the sand.

Where pits have been for a long time unworked and a cliff of Crag has been left exposed, the porous rock has served as a passage for surface-water, which oozes out from the face of the section. Here the staining can be directly associated with lines of flow. In some instances the iron-oxide has cemented the sand and shells together, and, where a part of the cliff has been overhanging, ferruginous stalactites and stalagmites have formed. This is well shown in the pit below the church at Chillesford. The stalactites are hollow tubes, frequently branched, and water can now be seen dripping through them.

One case of infiltration is worthy of special mention. It occurs at the base of the section at Beaumont Hall, where the Crag rests directly upon the London Clay. The sand and shells are black, and so thick is the encrusting material that no part of the original fragments can be seen. On treating this material with hydrochloric acid the calcareous interior is removed, but a hollow cast is left composed of iron-oxide. The carbon dioxide, liberated by the action of the acid on the shell, buoys up the cast so that it floats on the surface of the liquid.

Casts of shells are produced which often retain their characteristic markings. Even perfect examples of *Echinocyamus* and polyzoa can be obtained in this way, and some of the latter, such as *Biflustra* and *Cellaria*, show all the delicate features of the original organisms.

The following analyses, made by Mr. C. C. Moore, F.I.C., of Liverpool, show that the black encrusting material is slightly phosphatic:—

No. I refers to the black material from Beaumont;

No. II, given for comparison, is from the same pit, but the material was obtained from the interior of a large *Fusus*;

No. III shows the composition of a lighter-coloured Crag from Oakley.

	I. per cent.	II. per cent.	III. per cent.
Silica, etc. insoluble in hydrochloric acid	44·95	41·58	59·63
Soluble in hydrochloric acid:—			
SiO_2	trace	none	none
Fe_2O_3	5·72	7·73	16·37
Mn_2O_3	·21	trace	trace
$CaCO_3$	48·21	49·82	23·16
MgO	·08	·13	trace
P_2O_5	·21	trace	trace

The abundance of glauconite in the Crag makes it highly probable, as suggested by M. Van den Broeck,[1] that the decomposition of this mineral is the main source of the iron-oxide which forms the staining-material of these beds.

In all places where the Red Crag is exposed, it is seen to be composed of a loose shelly sand. Pebbles occur sporadically, ranging up to 3 or 4 inches in diameter.[2] Flint-pebbles are by far the commonest; they are usually very well rounded. A peculiar hard, brown chalk also occurs along with the flints. Other pebbles consist of pink quartzite, chert, and phosphatic nodules. Rolled clay-galls are found abundantly in most localities, coated with sand-grains, and resembling exactly those which are now being formed on sandy beaches bordering clay-cliffs.

Rolled specimens of a fairly coarse dark brown sandstone may be collected throughout the series, and can be matched with the Diestian Sandstones of Kent. It is not uncommon to find these pebbles bored by molluscs.

A finer-grained dark sandstone also occurs, which contains an abundance of mica. This may be the 'mica-schist' recorded by the late John Brown, of Stanway, as occurring at Beaumont.[3]

The chief object of this communication, however, is to record the rarer constituents to be found in the Crag sands.

In order to concentrate the rarer minerals, the sands were fractionated by means of high-density fluids. At first dilute hydrochloric acid was used, to get rid of the carbonates and to remove the iron-staining from the grains. It was found necessary, however, to treat the material with hot concentrated hydrochloric acid in order to clear the grains for examination. Even prolonged boiling in strong hydrochloric acid was not sufficient for the black material from Beaumont. Possibly some of the minerals readily soluble in hydrochloric acid have been removed by this treatment.

Twenty-five grammes of ordinary Red Crag from Beaumont was treated with concentrated hydrochloric acid. The insoluble part was then divided into fractions by means of Rohrbach's solution:—

	·102 gramme,	or ·4 per cent.,	had a density greater than 2·7;
	·622 „	or 2·5 „	„ „ less than 2·5;
while	12·25 grammes,	or 49 „	„ „ between 2·5 & 2·7.

[1] 'Du Rôle de l'Infiltration des Eaux Météoriques dans l'Altération des Dépôts superficiels' Internat. Geol. Congr. (Paris, 1878) Comptes Rendus, p. 188.

[2] A block of flint, cubical in shape and 15 inches across, may be seen lying on the floor of the large pit near Sutton Windmill; and Mr. Harmer states that he met with two or three large unworn flints, weighing 10 or 12 lbs., at Oakley.

[3] He also enumerates agate, chert, septaria, quartz (milky variety), quartz (highly crystalline like that of the Lickey), and flints from the Chalk: Quart. Journ. Geol. Soc. vol. xv (1859) p. 41. See also Prestwich, *ibid.* vol. xxvii (1871) p. 326, where he mentions a large fragment of red granite as occurring at Trimley.

In this sample quartz makes up about half of the total weight of the Crag.

Very much larger quantities were afterwards separated by means of Klein's solution (borotungstate of cadmium).

The fraction of a density above 3·28 contained zircon, rutile, cyanite, andalusite, corundum, garnets, ilmenite, and leucoxene.

The zircon occurs principally as small grains, averaging ·2 millim. in length. The majority of the crystals have sharp clear outlines, but others are rounded or oval in form. This, however, cannot be regarded as the result of abrasion by subaerial agents, as precisely similar rounded grains are found enclosed in the mica which comes down with a lighter fraction. The zircon itself usually contains many inclusions—long brown needles—hexagonal in section, and frequently oriented so that their long axes are parallel to the pyramidal faces.

Dark-brown or reddish crystals of rutile are also common. Most of them are very small, only a little larger than the zircons. Occasionally larger grains are found, having a diameter of ·5 millim. Usually the grains are angular and show crystalline faces, but rounded forms occur among the larger grains.

Cyanite is fairly plentiful, both as rounded and angular grains. The latter are mostly long rectangular prisms with strong cleavages, and often crowded with inclusions of zircon and rutile. The angle of extinction, measured from the prism-faces, is about 31° 30′. Some specimens exhibit a fibrous structure, and appear faintly blue under the microscope. The inclusions usually lie in lines which show extinction when parallel to the cross-wires of the microscope.

Andalusite is not common. It occurs as long, clear rectangular crystals, showing straight extinction and having a bright shagreen appearance.

Corundum occurs as brown or yellow crystals, mostly well rounded.

Garnets are so plentiful in the heavy fraction that the material in the mass has a strong pinkish colour. The grains are nearly always well rounded, and range up to and above ·5 millim. in diameter. They contain many inclusions.

Ilmenite occurs both as angular and rounded grains. It shows the characteristic greyish-black metallic lustre by reflected light.

Leucoxene accompanies the ilmenite as large, white, opaque grains. Sometimes the centre of a grain is black with a white border.

The material separated out by a solution having a specific gravity of 3 consisted almost entirely of

Tourmaline. The grains vary much in colour, but green predominates—emerald-green, pistachio-green, blackish-green; but many are yellow, brown, purple, and a few deep cobalt-blue. The green varieties are mostly angular in form, and often fibrous; the others are, almost without exception, well rounded.

The next fraction, with a density slightly less than 3, contains very little but mica and glauconite.

Both biotite and muscovite occur, though muscovite predominates. Associated with the micas is a dark-green biaxial mineral exactly resembling a mica: it is probably sericite.

Glauconite comes down with this fraction as well as in succeeding separations, even in those lighter than quartz. The heavier forms are opaque, but some of the lighter are translucent and even transparent. By reflected light the opaque varieties are dark-green, with white bands. They often retain the shape of foraminifera, of which they have formed casts.

The felspars, having a density approximating to that of quartz, are liable to be lost; but in the examination of many slides I have found microcline, orthoclase, labradorite, and albite.

Quartz. Even after treatment with strong hydrochloric acid, many of the grains retain a thin staining of iron-oxide. The larger grains only are well-rounded, and some have a very high polish. In size they range from ·05 to 1·5 millim. Inclusions are very common; some grains contain so many that they come down with the heavier separations. Apatite is of very frequent occurrence. Most of the grains are colourless, but amethyst- and amber-coloured specimens may be found. In a few cases only was there noticed a trace of secondary crystallization. Small angular pieces of flint and chalcedony are not infrequent.

The fraction having a specific gravity less than that of quartz consists mainly of glauconite and flint.

In some localities, as at Walton and places to the south of it, the Red Crag is overlain by sands and gravels. A separate examination of these revealed precisely the same constituents as those enumerated from the Red Crag. The only distinctions that I could detect were that they contained few or no shell-fragments; they show very little staining, and the larger pebbles were more numerous. Their general appearance suggests that the Red Crag material has been sifted by strong currents, the finer stuff and shells being removed, and the larger fragments left.

Norwich Crag (Icenian).

More than 3 lbs. of Norwich Crag was treated with heavy fluids in order to concentrate the minerals. Large fractions were obtained, and these have been thoroughly examined with a view to detecting possible differences between the inorganic constituents of the Red and Norwich Crags.

All the minerals stated as occurring in the Red Crag have been found in the Norwich Crag; the latter contains more mica, the grains are not so heavily stained with iron-oxide, and a fine muddy material coats the sand-grains.

Lithologically the Red and Norwich Crags must be regarded as forming one series, deposited under somewhat similar physical conditions.

Chillesford Sand.

Specimens were examined from two localities: the pit behind Chillesford Church, and the brickfield at Aldeburgh, where the sand is seen underlying Chillesford Clay. The minerals from these two localities are exactly the same, the only difference being that the grains are somewhat larger at Aldeburgh.

The sand was fractionated with borotungstate of cadmium, and the various separations were examined separately.

The following minerals occur:—Zircon, rutile, garnet, andalusite, ilmenite, leucoxene, tourmaline (green, blue, and yellow), biotite, muscovite, a green mica, plagioclase-felspars, quartz, and flint.

In striking contrast with the Crag sands, it will be noted that no glauconite was found.

Mica is very abundant, especially muscovite; and grains of flint are rare. Ferro-magnesian minerals except biotite are absent.

Nearly all the minerals enumerated in the foregoing pages are stable in composition, and capable of transport for long distances without decomposition. It would be a fair inference to assume that they have come from a distant source, and probably had their origin in rocks which have undergone extensive metamorphism. Whether they have been directly derived from such rocks would be hard to prove, but the frequent inclusions of zircon, rutile, and other secondary minerals in mica and other substances favours this view.

Discussion.

Mr. H. W. Burrows agreed with the Author's general contention that the Upper Red Crags show a succession of oldest to newest from south to north. This, he believed, could be demonstrated in detail: the pits at Butley being cited as an illustration. There seemed to him a peculiar fitness in the fact that the Author, who had endeavoured to demolish the seven zones established by Prestwich for the Coralline Crag, should now replace them with an equivalent number for the Upper Crags. According to the Author, the whole of the Coralline Crag could be included under one phase—Gedgravian; while it was necessary to define as many as seven distinct zones for

the Upper Crags. The relative values of these subdivisions were by no means equal; and it seemed to him that, if a new term be needed for Coralline Crag, the classical locality of Sutton should take precedence of Gedgrave.

It was difficult to see how the Author's view of oblique bedding could be entirely accepted, having regard to the reversal in obliquity so often seen, and particularly well exhibited at Butley Priory. The speaker alluded to the opinion of the late Dr. Paul Fischer, expressed in conversation at Bordeaux, that the sinistral and dextral forms of *Neptunea antiqua* should be regarded as distinct species. The theory expounded by Mr. Lomas did not appear to offer a complete explanation of the oxidation of the Crag, for it was not clearly explained how it was possible to find so much glauconite in the Crag, if oxidation was due to its decomposition, seeing that where the beds were reddest, glauconite was often most abundant. It was to be hoped that Mr. Kendall would publish his list of the Walton fauna, which would be a valuable addition to our knowledge of faunal distribution in the Crags.

Prof. Sollas congratulated the Author on the success with which he had evolved a connected history from materials so fragmentary as those of the Crag. The shifting of the area of deposition was an important phenomenon, and might be detected in some of the older systems. While false-bedding occurred in beach-deposits, it was far from being exclusively confined to them, and could not therefore be trusted as an indication of littoral conditions.

The President, Mr. P. F. Kendall, Mr. Whitaker, and Mr. Lomas also spoke.

The Author, after thanking the President and Fellows for their kind reception of his paper, said he was glad to find that most of those who had joined in the discussion were able to accept the conclusions which he had reached. Mr. Kendall had very generously consented to allow him to publish his valuable list of Walton shells, compiled some years ago, and this would add greatly to the usefulness and interest of his own lists from Beaumont and Oakley.

Replying to Mr. Burrows, he said that he had given in his paper his reasons for the division of the Red Crag into zones. He employed the term Gedgravian because Gedgrave is the only locality at which none but Coralline Crag deposits occur. At Sutton, both the Coralline Crag and the Red Crag are present, and if the designation Suttonian be used at all, it should rather be for the latter. Nevertheless, for the reasons given, he preferred the term Newbournian for Wood's Red Crag zone of Sutton.

The minerals found by Mr. Lomas in the Crag sands were all common in the Pliocene of Belgium, having been derived, according to M. Rutot, from the Ardennes, garnets, 'en petits cristaux,' being specially abundant. There is much to connect the English Crag-beds with the Rhineland. The cross-bedding of the Crag in the Butley Priory pit is precisely like that which is being produced in a former estuary of the Maas, near the Hoek van Holland, now being silted up with shelly sand.

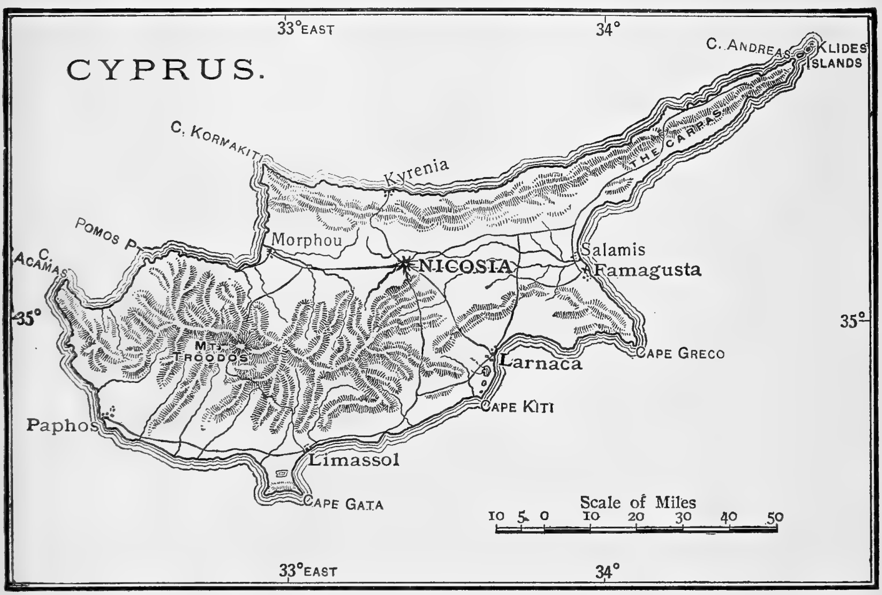
38. A Description *of the* Salt-Lake *of* Larnaca *in the* Island *of* Cyprus. By C. V. Bellamy, Esq., F.G.S., A.M.Inst.C.E., F.R.Met.Soc., Director of Public Works, Nicosia. (Read May 9th, 1900.)

[Plate XXXIX.]

Much interest has from time to time been evinced in the salt-lake of Larnaca in the island of Cyprus, and many have been the surmises as to the origin of the salt. No decided information on the subject has been yet recorded, so that the Government of Cyprus, taking advantage of the presence of Dr. Otto Maas of Munich University, who was visiting the island in the interests of Marine Biology, instructed the present writer to conduct such investigations as would lead to a settlement of the question. The results of these investigations as set forth in the following pages may be of interest to the Geological Society.

The town of Larnaca is situated about midway along the eastern half of the southern coast, on the bay of that name. It is at present the chief port of the island, nearly all the trade of Nicosia, the capital town, passing through it. Its ancient name was

Fig. 1.—*Map of the island of Cyprus.*



Kitium, and its other names at the present day are Scala and Marina.

About a mile or more to the south-west lie the salt-lakes or salines which form the subject of this paper.

(1) Topography of the Salt-Lake. (See Pl. XXXIX.)

The coast-line is generally low-lying or undulating, and in the neighbourhood of the salt-lake is but slightly diversified. On the eastern or south-eastern side, between the lake and the sea-shore, a stretch of nearly level country occurs for a width of 1 to $1\frac{1}{2}$ miles: this belt is covered with low brushwood, interspersed with patches of bare ground.

During the winter these bare spots are covered to a depth of a few inches with water, in some cases fresh, in others brackish, and in others again of a saltness nearly equal to that of the lake itself. Southward they extend to form a number of backwaters of considerable area, fed by streams which only flow immediately after heavy rains, and have no existence for the remainder of the year. These shallow lakes, although they now have no direct communication with the sea except during periods of abnormal rainfall, may lead us to the conclusion that they, in common with what is now the salt-lake, formed, at some remote period of prehistoric time, a somewhat extensive arm of the sea; but they now dry up as the summer approaches.

Farther south the land gradually rises till the sea-shore is encountered in the neighbourhood of Cape Kiti, the ancient Dades, near which stands a mediæval watch-tower, on the site probably of a much older Pyrgos or land-mark for mariners. On the south-west lie the fertile gardens of Perivolia, Kiti, and adjoining villages. Westward the land rises in gradual undulations to the watershed, situated at distances varying from 1 to 6 miles from the coast, where the soil is arable and mostly given to the cultivation of wheat and barley; and northward a low-lying littoral stretches away some distance beyond the town of Larnaca, occasionally diversified with marshes and swamps. On the south-western shore of the lake stands the Moslem monastery known as the Ummal Harám Tekké, where lies buried the Prophet's aunt; it is for the Moslems a place of pilgrimage, and a most holy spot. The soil around the lake is of a calcareous, sandy nature, containing, and, in fact, largely composed of, fragments of marine shells. Between the lake and the sea the ground is so salt as to preclude cultivation, and nothing but coarse brushwood ekes out an existence in it, but on the other sides the soil is of average fertility.

The configuration of the country comprising the watershed of the lake is of the nature of an irregularly-shaped basin, having its eastern side cut away to form a kind of lip; in the lowest part of this hollow the salt-lake has accumulated. Down the sides of the basin flow streams, the two most important of which descend the valleys in which the village of Kalokhorio is situated on the one hand, and

the hamlet or farm of the Pasha Chiftlik on the other, and they at one time discharged into the salt-lake, or the estuary the site of which the lake now occupies; but their waters have been intercepted by artificial channels, and are now conducted on the north to the sea direct, and on the south to the backwaters already described, and thence to the sea (see Pl. XXXIX, & fig. 2, p. 748.)

(2) Geology of the Neighbourhood.

The geological strata in the neighbourhood of the salt-lake have been described by Prof. Albert Gaudry in his memoir on the 'Géologie de l'Ile de Chypre,'[1] and by Dr. Unger in his monograph 'Die Insel Cypern' Vienna, 1865, written in collaboration with Dr. Kotschy. They consist chiefly of (i) conglomerates; (ii) shelly sands and gravels; and (iii) marls or calcareous clays.

(i) Conglomerates.

The conglomerates contain waterworn fragments of older rocks, flints from the Oligocene limestones, jasper from the metamorphic rocks, and fragments of greenstone and ophitic rocks, besides numerous fossils, the whole cemented together by calcareous matter sometimes hard and sometimes friable. Dr. Unger describes the formation thus (*op. cit.* p. 10):—

'The basin at Larnaca occurs in the youngest of the marine sandstones;'

and quoting from Prof. Zittel he adds :—

'The formations of Larnaca belong to the youngest division of the Tertiary formation; a division which has been found in numerous places on the shores of the Mediterranean, and which has, especially in the case of Rhodes and Sicily, acquired some fame by the numbers of fossils found in it. The numerous well-preserved fossils of Larnaca bear an extraordinary resemblance to the mollusca still living in the Mediterranean. Out of 146 specimens, only four were found to be those of completely extinct species. . . . . [The character of the fossils] shows the formation to have been deposited in shallow water.' (*Op. cit.* pp. 46–47.)

The individual components of this conglomerate vary in dimensions from the size of a walnut to that of an apple. In some parts it is very compact, but in others it passes gradually into a fine sandstone, and in such places the fossils may be extracted with ease, so much so in fact that they frequently fall out by the mere disintegration of the mass consequent upon rain, which carries away the softer matter and leaves large and small fossils lying together on the surface. This lighter material is also rich in the remains of minute organisms, such as polyzoa, corals, and foraminifera. The beds scarcely deviate in the slightest from the horizontal position.

[1] Mém. Soc. Géol. France, ser. 2, vol. vii (1862) pp. 219 *et seqq.*

Fig. 2.

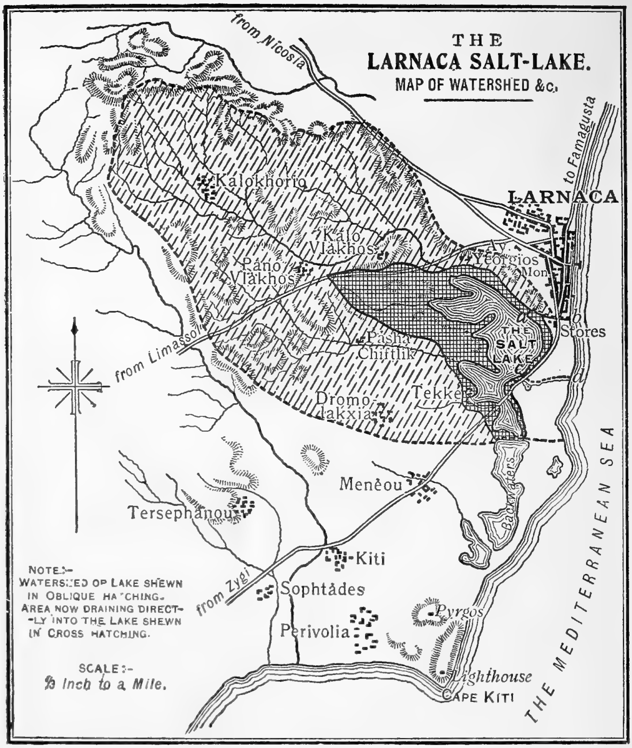
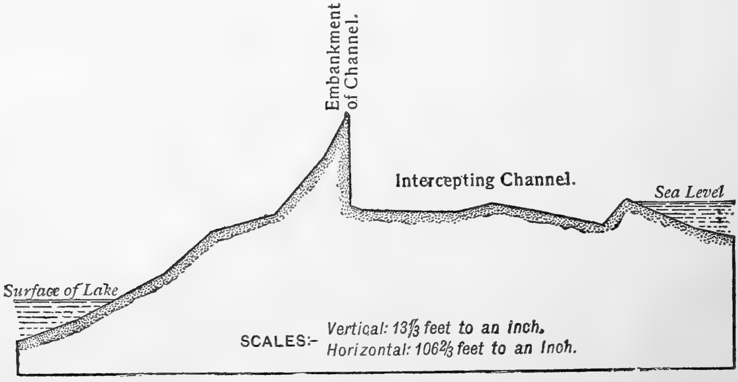


Fig. 3.—*Section along a–b (Pl. XXXIX & fig. 2) from the lake to the sea.*



(ii) Shelly Sands and Gravels.

The shelly sands and gravels are of a yellowish colour, and their constituents are almost identical with the finer material incorporated in the conglomerate—foraminifera, polyzoa, *Cladocora cæspitosa* being in the majority; while fragments of the larger shells of molluscs and crustacea, specimens of which are still to be found in the adjoining seas, also abound.

(iii) Marls and Clays.

The marls and calcareous clays contain abundance of carbonate of lime, but few organic remains, and effervesce profusely when tested with acid. They vary in colour from bright and pale yellow to pale grey or slate-grey. They are compact, and contain much fine granular matter; moreover they are frequently laminated and indurated to an extent resembling shale. When their surfaces are exposed, an efflorescence appears, owing to the presence in them of sulphate of soda and magnesia.

They probably bear a close lithological resemblance to the 'Argile plastique' of French authors, though it is doubtful whether these Larnaca deposits are of sufficient purity to render them useful in pottery.

(3) Watershed of the Lake.

Reference may be made here to the accompanying map of the watershed of the salt-lake (fig. 2, p. 748).

The high ground as indicated by the hill-shading will be seen to encircle the watershed on all but the southern and south-eastern sides, where the backwaters or lagoons are formed in winter. This will better explain the reference to the 'basin-like' nature of the area (p. 746), the 'lip' being located on the south-eastern shore of the lake: as, although no distinct eminences exist, on the southern side the land rises gradually towards the villages of Menéou and Dromolakxia to a point well above sea-level.

(4) Level of the Lake as compared with that of the Sea.

In order to ascertain correctly the difference, if any existed, between the lake and the sea, a series of levels were taken between the points *a* and *b*, from which the accompanying section (fig. 3) has been prepared. It commences on the shores of the lake a short distance west of the Salt-stores and Guard-house, joins the northern intercepting channel, and proceeding down the centre meets the seashore at *b*, where the channel discharges.

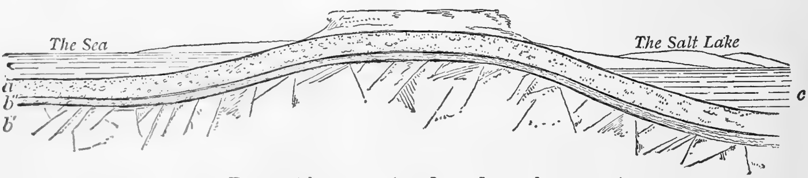
It will be seen that the difference between the two surfaces is very considerable: at 10.35 A.M. on December 18th last this difference was found to be 7·07 feet. On the following day another section was taken between the points *c* and *d*, situated about midway between the Stores and the Tekké, and following approxi-

mately the watercourse shown to run from a small backwater to the sea (Pl. XXXIX, & fig. 2, p. 748). At 12 noon it was found that the surface of the lake was 6·90 feet below that of the sea. Allowing, therefore, for the variation of tide, the conclusion may be drawn that the difference is about 7 feet, and that the deepest part of the lake is probably about 10 feet below mean sea-level.

(5) Barrier between the Lake and the Sea.

The nature of the geological formation already described indicates that the lake is divided from the sea by a barrier composed for the most part of shelly sand overlying a bed of stiff calcareous clay, and at intervals along this barrier masses of conglomerates, sometimes hard and sometimes friable, occur: so that the barrier is only porous or permeable in a few places. The appended sketch (fig. 4) may help to illustrate its nature.

Fig. 4.—*Section across the barrier between the salt-lake and the sea.*



a = Permeable strata (sands and conglomerates).
b' = Impermeable stratum (clay).
b'' = Layer of watery matter.

(6) Results of a Borehole.

The manner in which these strata overlie each other was ascertained by means of a borehole driven on the shores of the lake near the Salt-stores. It was shown by this means that upon the surface was a thin layer of yellowish calcareous or shelly sand about 12 or 18 inches thick, then came a thin layer of black mud corresponding to the deposit in the bed of the lake. Between the depths of 2 and 10 feet shelly sand again appeared, but intermixed with argillaceous matter, or more strictly calcareous matter in a plastic state, as it consisted largely of carbonate of lime. This was somewhat stiff, and not easy to penetrate; but between 10 and 12 feet below the surface it became very soft, and contained much water distinctly salt. The material brought up by the boring-apparatus was of the nature of 'slurry' or watery mud. From 12 to 15 feet of stiff calcareous clay was met with, and beyond this depth the material became so hard as to clog the boring-rods. It was with the greatest difficulty that they could be turned, and they were only withdrawn by pouring water down the tubes to soften the matter. Ten days after the date on which this boring

was made, it was found that around the borehole a pool of distinctly salt water had formed, indicating without doubt that the perforation of the stratum superincumbent upon the layer of watery matter had operated much in the same manner as an artesian-well boring, and that relief having been furnished to the subterranean salt-water, it had risen to the surface through the borehole, welling up sufficiently to form a pool.

(7) Origin of the Salt.

Regarding the origin of the salt, it may be as well here to consider the opinions expressed by Dr. Unger and Prof. Gaudry.

Dr. Unger expresses himself much as follows [1] :—

'Every one who makes a personal inspection of the salt-lake will come to the conclusion that the salt is not formed by the leaching-out of salt from the saliferous soil by the rain-water which streams over it; nor by subsequent evaporation. If such were the case the quantity of salt would annually diminish, and the supply become eventually exhausted, but there is an equal production and a constant supply of salt under similar and equal conditions: therefore the salt must be, as in other countries, the product of sea-water. The basin lies below the sea, so necessarily, by the porous nature of the soil that intervenes between the lake and the sea, sea-water percolates through to the lake, bringing the surface of the latter to the same hydrostatic level. In the winter-time, when evaporation is less and there is even some influx of fresh water, the level of the salt-lake must become higher than that of the sea, and therefore it can be explained how it was considered necessary to conduct surplus water from the lake by means of channels to the sea. In summer-time the inflow of sea-water cannot compensate for the greater evaporation then proceeding; and later, by a diminution in the supply of sea-water, a total desiccation of the contents of the lake must take place... If the bottom of the lake were even in only a few places formed of a more porous material, the evaporation which we know takes place could not be thought of.'

Prof. Gaudry, on his part, offers the following solution [2] :—

'My opinion of the way in which the salt-lakes of Cyprus are fed is this. In winter, while the southerly and south-westerly winds blow strongly, the sea rises on the shore a little above its natural level. No doubt the waters then penetrate the barely consolidated Quaternary sands which border the Mediterranean; lakes are thus formed in the low-lying areas near the shore. Many Cypriotes believe that the salt-lakes are fed by the rain-water coming down from the mountains; they base this opinion on the observation that the more rainy is the winter the more considerable is the production of salt. It may be answered to this that the rocks around the salt-lake of Cyprus over which the rain-water flows are white marl, calcareous sands, aphanites, and ophitones, and that these rocks do not supply chloride of sodium in any appreciable quantity. No doubt it is a mistake to suppose that the production of salt is greater in rainy than in dry seasons. In the years when it rains most the surface of the lakes becomes larger; so when the heat comes the deposit of salt covers a larger area. A greater quantity is collected without the entire mass being more considerable.'

Dr. Unger's explanation appears to be nearer the correct solution; but Prof. Gaudry's is also of interest, and the theory which he propounds of the sea-water banking up slightly during the winter

[1] 'Die Insel Cypern' Vienna, 1865, pp. 9–10.

[2] Mém. Soc. Géol. France, ser. 2, vol. vii (1862) p. 273.

is not altogether improbable, though there is a doubt whether the operation is sufficiently marked to influence the level of the salt-lake.

(8) Section of Barrier.

Reverting to the section of the barrier represented on p. 750 (fig. 4), it may be concluded without hesitation that the strata *a* form a conduit through which the water from the sea is constantly percolating, on its way to the depression *c*, where at certain periods of the year it makes its appearance above the surface of the ground and accumulates as a salt-lake. It has been seen, in considering the results of the boring, that, immediately overlying the impervious stratum of clay (b'), a belt of watery material is met with, thus indicating that there is a steady and uninterrupted flow of water at intervals through the lip of the basin and over the bed of clay.

(9) Inflow of Sea-water.

The inflow of sea-water is not sufficient, by reason of the occurrence of impervious masses of conglomerate in the strata *a*, to raise the surface of the lake to a height corresponding with that of the sea. Before this could be arrived at the summer intervenes and evaporation is started, whereby the water in the basin passes off in the form of aqueous vapour, leaving the residue to accumulate in the form of salt. The inflow of sea-water is constantly in progress, but it may be aided during the winter by the absorption of water in the soil, consequent upon rain, setting up a certain amount of capillarity. Evaporation is constantly proceeding in greater or lesser degree in the air, so long as the humidity of the latter remains below the point of saturation; but this evaporation is developed to a remarkable extent during the intense heat of the Cyprus summer, and then proceeds in a greater degree than in winter.

When the winter sets in and the temperature falls, the evaporation diminishes: with the aid of a few showers of rain the supply of sea-water overcomes the loss by evaporation, and water begins to make its appearance in the bed of the salt-lake, where only a short time previously there was nothing but the crystallized saline residue.

Thus the formation of salt is continually proceeding: always an inflow of sea-water through the soil, always followed by the evaporation of the water. This process must from year to year result in a greater density of the water in the basin and a consequent greater accumulation or precipitation of salt, the operation resulting in a constant and unfailing supply of that commodity.

(10) Inflow of Fresh Water.

In regard to the inflow of fresh water, it should be explained that Prof. Gaudry visited Cyprus in the year 1853 and Dr. Unger about ten years later, and there is reason to believe that in those days

much of the rain-water, falling in the Kalokhorio and Pasha Chiftlik Valleys, found its way into the salt-lake, thereby increasing the area of the latter to the detriment of salt-collection. Prof. Gaudry, in fact, distinctly states with regard to the channels designed to carry off surplus water (by which no doubt he refers to the intercepting channels, or to those which at that period corresponded to those now existing) that 'they are now for the most part filled up.' It is very probable that much the same state of things existed ten years later, and even up to the time of the British occupation in the year 1878. Now, however, the artificial channels, shown in the map (Pl. XXXIX) in heavy lines near the Ummal Harám Tekké on the south and the monastery of Ayios Yeorgios on the north, intercept flood-water and convey it to the sea. Therefore the only water which now collects in the lake derives its origin, either by percolation from the sea, or from the rain which falls upon the surface of the lake itself or upon the land in its immediate neighbourhood. This explains its present contracted area, as compared with the prevalent conditions in Prof. Gaudry's or Dr. Unger's time.

(11) Channels to carry off Surplus Water.

In order that the maximum of salt may be deposited, it is necessary that the minimum of fresh water should be admitted. The existence of 'channels to carry off surplus water' from the lake itself, as mentioned by Prof. Gaudry, is superfluous, since, before they could operate, it would be necessary for the surface of the lake to rise at least 7 feet above its present level, thus submerging a wide area of country and probably obliterating all trace of the present lake.

In the embankment which carries the public road from Larnaca towards Kiti, culverts are found which have been doubtless constructed to serve the purpose alluded to, but their operation is the reverse of that designed for them: they admit water, which, not being of the same degree of saltness (if salt at all) as the contents of the lake, has a detrimental effect upon the latter, though to so small an extent that its influence cannot be observed.

(12) Influence of Rain upon the Lake.

An important point, namely the influence of rainfall upon the contents of the lake, has so far not been thoroughly discussed, and in dealing with this subject a reference should be made to the accompanying drawings. Plate XXXIX is a diagram on a large scale of the lake and its immediate neighbourhood. In this plan, as in the case of fig. 2 (p. 748), the salt-lake proper is shown with slightly darker shading, to distinguish it from other sheets of water in the vicinity, and more especially from the backwaters to the southward. These latter, though in a sense salt-lakes also, are not exploited for revenue purposes, no salt being ever collected from them.

(13) Catchment of Lake and Areas.

But the chief interest will be centred in fig. 2, p. 748. On this map the original watershed or catchment of the lake is defined by oblique hatching, and its entire area is computed at 22 square miles, say 14,080 acres. The country which now drains directly into the lake is cross-hatched, and its area is about 2·4 square miles, say 1,536 acres; while the surface of the lake occupies about 2·1 square miles, say 1,344 acres, and its circumference is about $10\frac{3}{4}$ miles. Of the 22 square miles comprising the catchment, the surface-water from $17\frac{1}{2}$ square miles is collected in the catchwater or intercepting channels, and carried away to sea without being permitted to enter the lake. Therefore only the rain falling within an area of $4\frac{1}{2}$ square miles, comprising the surface of the lake and that of the land within the cross-hatched area, has a direct influence upon the contents of the lake.

As to the cubical capacity of the lake, if it be assumed that the mean depth throughout is 1 foot, the contents will be, say, 77 million cubic feet (76,980,160 cubic feet correctly), which is equivalent to about 480 million gallons in round numbers.

(14) Rainfall.

A fall of 1 inch of rain produces $14\frac{1}{2}$ million gallons of water per square mile, and the amount of water collecting in the lake from the cross-hatched area, as well as that falling upon the surface of the lake itself as the product of 1 inch of rain, would therefore be $65\frac{1}{4}$ million gallons. In order to fill the lake to the height at which it stood at the time of observation, a fall of 7·35 inches would suffice.

The rainfall returns for Larnaca, the nearest point to the salt-lake at which there is a rain-gauge, show that from the end of August 1899 the following quantity of rain fell:—

	Inches.
September	0·50
October	1·27
November	4·52
December 1st to 19th	1·08
	7·37

This quantity corresponds very nearly to that sufficient to fill the lake, without taking into consideration the loss by evaporation or other causes.

It may be safely assumed that the net product of an inch of rain falling upon the surface of the lake would be 100 per cent., and that the run-off or surface-water from the cross-hatched area, allowing for infiltration or absorption, would be 50 per cent. of the rainfall.

This fall of 7·37 inches over an area of 2·1 square miles representing the surface of the lake would amount to $224\frac{1}{2}$ million gallons, and over the cross-hatched area of 2·4 square miles would

be $53\frac{1}{2}$ million gallons, or a total product of 278 million gallons. From this must be deducted the loss by evaporation for the period during which the 7·37 inches of rain fell, that is to say nearly four months, and the loss from this cause may be set down at 20 per cent. The net product of the rainfall between the first day of September and the nineteenth of December will therefore be about 223 million gallons.

It has already been assumed that the contents of the lake are 480 million gallons, and it has also been shown that only 223 million gallons was produced by rainfall. It is therefore not too much to say that the balance (257 million gallons), or considerably more than one half the contents of the lake, was derived from the sea.

There is, however, this much to be remembered, namely, that some portion of the rain absorbed by the land enclosed within the cross-hatched area comprising the watershed of the lake, after penetrating the upper surface of the soil, would find its way through subterranean passages into the lake, so that not all of the 50 per cent. allowed for infiltration would be lost. On the other hand, it is certain that the first few showers of rain falling within the area of direct drainage (cross-hatched) would be entirely absorbed by the parched soil, and the contents of the lake would, at the commencement of the rainy season, only be affected by such rain-water as fell directly upon its surface.

While this argument is based in the first instance merely upon an assumption as to the contents of the lake, there is sufficiently strong evidence for believing that at least 50 per cent. of the contents of the lake comes from the sea, and since therefore so much salt-water enters the lake, the origin of the salt is not far to seek.

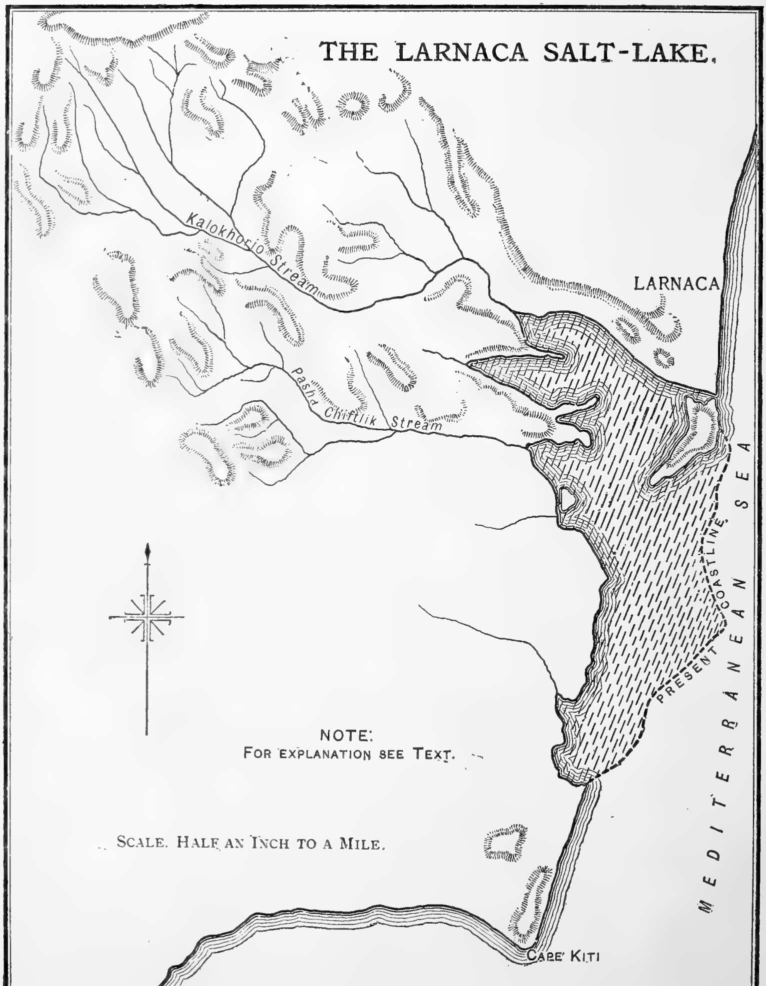
It has already been shown that the entire watershed of the lake covers 22 square miles; the product of 1 inch of rain over this area would be 319 million gallons. The mean annual rainfall for Larnaca for the five years 1893–97 was 17·87 inches. It is hardly necessary to point out that, but for the intercepting channels, the salt-lake would probably have no existence, and a wide area of country lying below sea-level would be submerged. It may be also inferred what serious consequences might arise from a breach in any part of the embankments which form the channels.

Again, this mean annual rainfall of 17·87 inches, falling within the area directly affecting the lake, would fill it more than twice over, and from this fact may be derived some idea of the rate of evaporation and infiltration, since it is conclusively proved that the lake must also be fed somewhat freely from the sea. That the surface of the lake does not rise to a height corresponding with that of the sea is accounted for by the fact that the 17 or 18 inches of rain do not fall at once, and that in the intervals between the showers evaporation takes place with sufficient rapidity to counteract the effect produced by rain and sea combined.

(15) The Lake on the Site of a former Estuary.

In this connection it will be interesting to refer to the last map of the series, namely fig. 5, on which is depicted an extensive arm of the sea on the site of the present lake and backwaters. If one could go back through past centuries to visit the scene of this paper towards the close of the Kainozoic Age, the appearance presented would probably correspond in some degree to that here shown. In like

Fig. 5.—*Map showing the ancient estuary which is now the site of the salt-lake.*



manner, should the intercepting channels fail to operate, or the sea encroach, a wide estuary (shown by hatching) of shallow water would be formed, and all trace of the salt-lake become obliterated.

(16) Forces operating upon the Lake..

It has now been demonstrated that there are two opposite forces perpetually operating upon the lake. The one, whose effect is to fill it, originates from the inflow of sea- and rain-water combined, acting respectively from above and below; and the other, whose effect is to empty it, is represented by evaporation, infiltration being a 'quantité négligeable,' as it may be concluded that the ground under and around the lake is already and continually saturated with moisture. An equilibrium between the two forces is probably never arrived at, and the level of the lake must be constantly varying. This much was noticeable from day to day during the progress of these observations, when a fresh dry wind was blowing from the north and north-east, whose capacity for absorbing aqueous vapour was indicated by the daily subsidence of the lake, when rain was absent.

(17) Rate of Evaporation.

It is matter for regret that there are no means of ascertaining accurately the extent to which these forces operate. The rate of evaporation in Cyprus has apparently never been measured; it can only be estimated very approximately. Experiments and observations in this direction would be interesting as well as of considerable value; and it would doubtless be proved decisively, by this and similar means, to how great an extent the sea contributes towards the filling of the lake.

(18) Salt-Harvest.

The salt-harvest commences during the month of August, that is to say, when the summer-heat is at the zenith of its power; but it is reported that the occurrence of one heavy shower at this time of year suffices to ruin the prospects of the collection entirely. This may be understood when it is realized that 1 inch of rain represents nearly one-eighth part of the contents of the lake, and falls to this amount not infrequently accompany a thunderstorm in the summer-time.

The quality of the salt collected in the Larnaca salines is of unusual excellence. It has from earliest history not only been famed for the important part which it plays in domestic economy, but has enjoyed a reputation for possessing valuable medicinal properties, and it is peculiarly free from grit or other foreign matter.

However justly or otherwise it deserves this reputation, there is much satisfaction in the knowledge that the lake must continue to be an uninterrupted and inexhaustible source of revenue to the island, and a large and remunerative traffic could be carried on if markets could be opened for the salt. The mode of collection is of the simplest possible description, and as Prof. Gaudry says in this connection: 'Tout se passe encore en Chypre comme en 1572' (*op. cit.* p. 273).

(19) Density of the Water.

Some interesting particulars regarding the water in the salt-lake, for which I am indebted to Dr. Otto Maas, are here appended:—

The density of the water in the lake was taken on December 19th, 1899, and was found to be between 10°·5 and 11° by hydrometer (areometer). The temperature of the water was 16°·50 Centigr. (61°·70 Fahr.), and of the air 15° Centigr. (59° Fahr.) at the time. This will be better understood when it is explained that the normal density of the Mediterranean is between 3°·35 and 3°·40 by the same instrument.

On October 20th, 1899, towards the close of the hot season and after only one shower of rain had fallen, the water was of too great a density to be recorded by the hydrometer. On the 28th of the same month, after heavy rain had fallen on two occasions, the density was found to be about 17° or rather less. On December 29th, heavy rain having fallen on the 23rd and 24th, the density was found to be 10°·2 and the temperature 14°·3 Centigr. On this latter date also the water rising through the borehole driven on the 19th of the same month was found to be of 8°·2 density.

(20) General Summary.

The following is a summary of the observations recently made:—

(i) The surface of the salt-lake, at what may be considered to be its winter-level, is 7 feet, and the bottom of the lake is 10 feet below sea-level.

(ii) The sea-water percolates through the soil between the upper surface of an impermeable stratum of indurated clay and the lower surface of a bed of sandy clay of a less impermeable nature; it filters through this latter stratum, rising to the surface to accumulate in a depression in the ground, and forms the salt-lake.

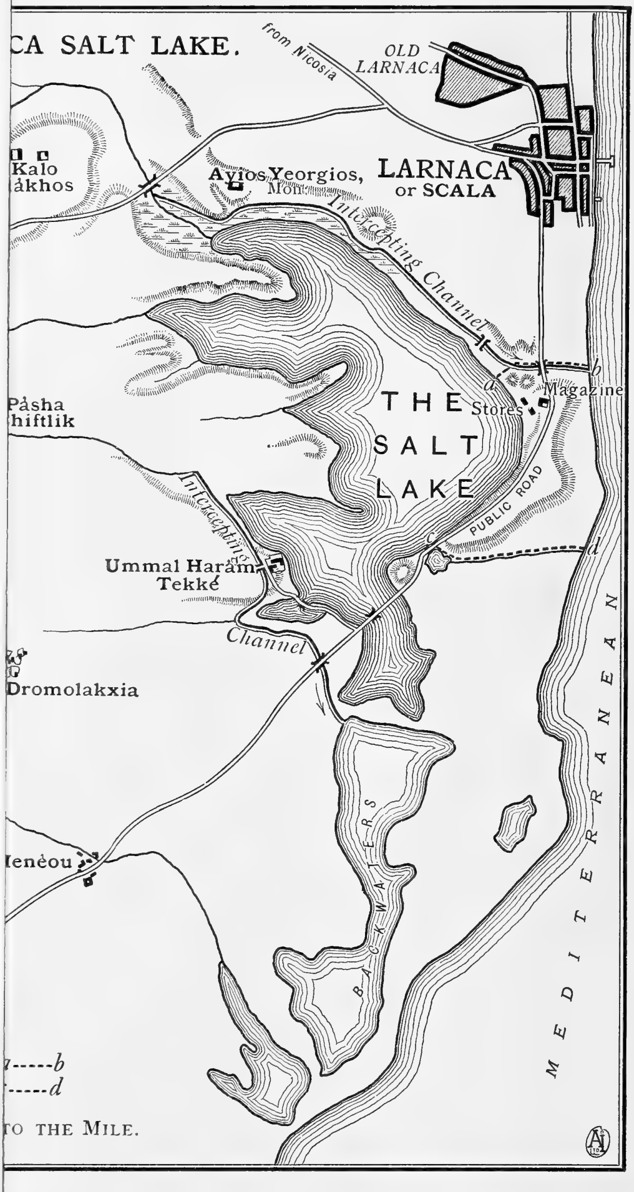
(iii) The subsoil salt-water (which rose to the surface of the lake-shore through the borehole recently driven) is of more than twice the normal density of the sea, and about 75 per cent. that of the water in the lake at the time of observation.

(iv) The bottom of the salt-lake is covered with an incrustation of salt overlying a layer of mud, consisting of the decaying remains of micro-organisms and mineral matter.

It is in conclusion the writer's pleasing duty to record his sense of obligation to Dr. Otto Maas, whose valuable assistance has contributed so largely to the preparation of the foregoing paper.

PLATE XXXIX.

Map of the Larnaca salt-lake and its immediate neighbourhood, on the scale of one inch to the mile.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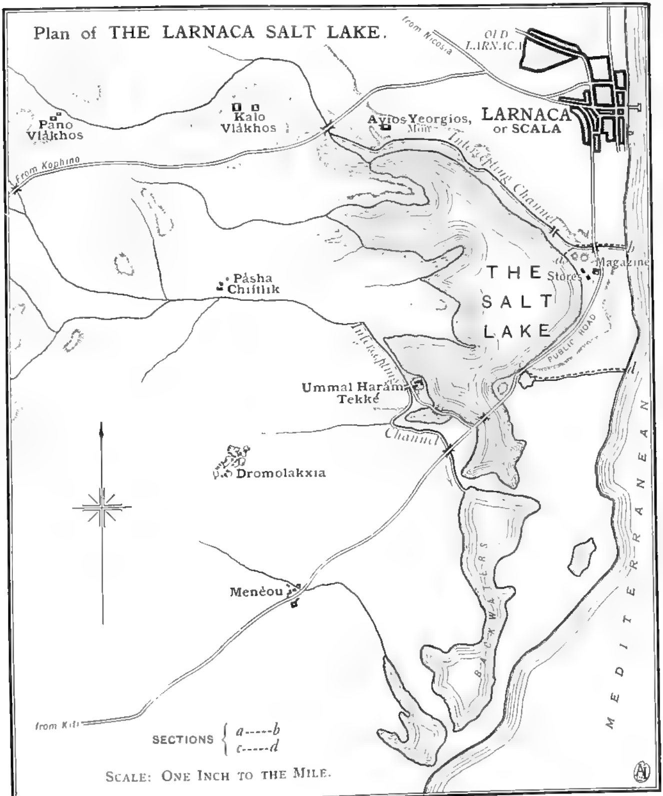
Plan of THE LARNACA SALT LAKE.
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LARNACA or SCALA
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Kalo Vlákhos
Ayios Yeorgios, Mill
Intercepting Channel
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SCALE: ONE INCH TO THE MILE.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LVI.

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1899–1900.

November 8th, 1899.

W. Whitaker, B.A., F.R.S., President, in the Chair.

Edward Kynaston Burstal, Esq., M.Inst.C.E., 38 Parliament Street, Westminster, S.W.; and William Selkirk, Esq., Beckermet (Cumberland), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Cornish Earthquakes of March 29th to April 2nd, 1898.' By Charles Davison, Sc.D., F.G.S.

2. 'On the Geological Structure of Portions of the Malvern and Abberley Hills.' By Prof. T. T. Groom, M.A., D.Sc., F.G.S.

The following specimens were exhibited:—

Specimens from the Lower Greensand of Shanklin (Isle of Wight), exhibited by E. A. Martin, Esq., F.G.S.

November 22nd, 1899.

W. Whitaker, B.A., F.R.S., President, in the Chair.

Frederick William Armstrong, Esq., Assoc.R.S.M., The Hill, Langport (Somerset); and Herman Alfred Roechling, Esq., C.E., 23 Highfield Street, Leicester, were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT, having requested all present to rise from their seats, expressed in feeling terms the sorrow felt by the Society at the unexpectedly sudden loss of an esteemed Fellow and genial friend, Dr. HENRY HICKS, F.R.S., V.P.G.S., to whose energy and perseverance the Quarterly Journal owed so many papers, and from whom many more valuable contributions might have been expected in the years to come. The following resolution had been passed by the Council that afternoon, and a copy thereof had been communicated to Mrs. Hicks with an expression of sincere sympathy:—

> 'That the Council desire to place on record their great grief at the loss which Geological Science and the Geological Society have sustained by the death of their Vice-President, Dr. Henry Hicks, who so recently occupied the Presidential chair, and so energetically attended to the welfare of the Society.'

The PRESIDENT then said that the Society had to deplore another severe loss in the person of their revered friend, Sir J. WILLIAM DAWSON, C.M.G., F.R.S., who died at Montreal on Sunday, November 19th. The Council had passed the following resolution:—

> 'That the Council have heard with deep regret of the decease of the old and valued Fellow of the Geological Society, Sir J. W. Dawson, who for ne rly fifty years has taken an active part in advancing geological knowledge in general, and more especially with regard to the great Dominion of Canada; and they desire to assure Lady Dawson, and the distinguished Fellow of the Society, Dr. George Dawson, of the Council's sincere sympathy in their loss.'

The following communications were read:—

1. 'On some Remarkable Calcisponges from the Eocene Strata of Victoria (Australia).' By George Jennings Hinde, Ph.D., F.R.S., F.G.S.

2. 'The Silurian Sequence of Rhayader.' By Herbert Lapworth, Esq., Stud.Inst.C.E., F.G.S.

The following specimens were exhibited:—

Eocene Calcisponges from Victoria (Australia), exhibited by Dr. G. J. Hinde, F.R.S., F.G.S., in illustration of his paper.

Rocks and Fossils from the Silurian of the Rhayader District (Central Wales), exhibited by H. Lapworth, Esq., Stud.Inst.C.E., F.G.S., in illustration of his paper.

An Album of Geological Photographs, exhibited by H. W. Monckton, Esq., F.L.S., F.G.S.

December 6th, 1899.

W. Whitaker, B.A., F.R.S., President, in the Chair.

Ernest Edward Leslie Dixon, Esq., B.Sc., 2 Thornford Road, Lewisham, S.E.; William Galloway, Esq., Professor of Mining in the University College of South Wales & Monmouthshire, 19 Newport Road, Cardiff; Ellis Philip Gilman, Esq., Assoc.R.S.M., 34 Ladbroke Square, London, W.; Robert Lockhart Jack, Esq., c/o The British Consul-General, Shanghai; William John Le Lacheur, Esq., B.A., The Wilderness, Tunbridge Wells; George Frederick Reader, Esq., Geological Survey of India, Calcutta; Philip Rufford, Esq., 19 Magdalen Road, St. Leonard's-on-Sea; Henry Vassall, Esq., M.A., Repton, near Burton-on-Trent; and Ernest Seymour Wood, Esq., 10[1] Old Court House Street, Calcutta, were elected Fellows of the Society.

The List of Donations to the Library was read.

Dr. Blanford said that he had been asked by Prof. Judd, who was unable to attend, to say a few words about certain photographs sent by Mr. E. H. L. Schwarz, and representing the Dwyka boulder-bed and the rounded and grooved underlying surface, in the neighbourhood of the Orange River near Hopetown and Prieska. The importance of these photographs lay in the evidence which they afforded on a disputed point. Dr. Sutherland and Mr. Griesbach had called attention to the evidence of ice-action presented by the Dwyka Conglomerate in Natal, and additional evidence had been brought forward by several observers, especially by Mr. Dunn from the Orange Free State and Cape Colony, and recently by Dr. Molengraaff from the Transvaal. Other observers, however, and especially the late Prof. Green, had disputed the glacial origin of the Dwyka Beds. The photographs now exhibited would, the speaker thought, convince most geologists that the phenomena presented were due to ice-action. The resemblance to similar photographs shown to the Geological Society in 1896 by Prof. T. W. Edgeworth David, and representing the beds corresponding to the Dwyka Conglomerate in South Australia, was noteworthy. Evidence of glacial action in Upper Palæozoic times had gradually accumulated from India, Australia, and South Africa, and there was a probability that similar indications existed in South America.

The following communications were read:—

1. 'On the Geology and Fossil Corals and Echinids of Somaliland.' By Dr. J. W. Gregory, F.G.S.

2. 'Note on Drift-Gravels at West Wickham (Kent).' By George Clinch, Esq., F.G.S.

3. 'On the Occurrence in British Carboniferous Rocks of the Devonian Genus *Palæoneilo*, with a Description of a New Species.' By Dr. Wheelton Hind, B.S., F.R.C.S., F.G.S.

The following specimens and photographs were exhibited, in addition to the photographs mentioned on p. iii :—

Rock-specimens, Fossils, and Photographs of Somaliland, exhibited by Dr. J. W. Gregory, F.G.S., in illustration of his paper.

Specimens and Cast of *Palæoneilo*, exhibited by Dr. Wheelton Hind, B.S., F.R.C.S., F.G.S., in illustration of his paper.

Flint-implements from Drift-gravels and Photographs of the same, West Wickham (Kent), exhibited by George Clinch, Esq., F.G.S., in illustration of his paper.

A Bunter Pebble, much decayed, from Coombe Warren (Surrey), 180 feet above O.D., exhibited by A. E. Salter, Esq., B.Sc., F.G.S.

December 20th, 1899.

W. Whitaker, B.A., F.R.S., President, in the Chair.

Ephraim H. Davies, Esq., B.Sc., Intermediate School, Builth; John William Jarvis, Esq., St. Mark's College, Chelsea, S.W.; and Henry J. Seymour, Esq., B.A., 16 Wellington Road, Dublin, were elected Fellows; Dr. Charles Abiathar White, of Washington (D.C.), U.S.A., was elected a Foreign Member; and M. Michel F. Mourlon, of Brussels; Prof. Henry Fairfield Osborn, of New York; and Prof. Gregorio Stefanescu, of Bucharest, were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

Dr. P. L. Sclater exhibited a large diagram of a new bore lately made for the Zoological Society of London, in the bottom of the old well in the Society's Gardens, Regent's Park.

The original well was dug in 1834 to a depth of 180 feet, and a bore-hole sunk 10 feet farther: it is stated that the water then rose to an ordinary level of 120 feet from the surface of the ground. The bore, it is believed, was subsequently carried to a depth of 274 feet.

Some years ago the sand from one of the formations penetrated into the bore and rendered the pump useless, and acting under the advice of Mr. Henry Law, C.E., the Council of the Society determined in 1897 to have a new bore made in the old well, it being pronounced impracticable to clear the existing bore without incurring a larger expenditure. A contract for the construction of a new bore was accordingly made with Messrs. Isler & Co. In spite of many difficulties encountered during the progress of the work, this has been successfully accomplished; and an abundant supply of pure water from the Chalk is now being pumped into the High-level Reservoir at the southern corner of the Zoological Gardens. No fossils were found.

The following table of particulars has been supplied by the contractors :—

	Feet.	Inches.
Dug Well	170	0
Concrete	8	0
New Bore-hole	294	6
Total depth	472	6

Strata traversed by the New Bore :

	Feet.	Inches.
1. Grey Sand	1	0
2. Mottled Clay	5	0
3. Green Sand	9	0
4. Sand and Pebbles	8	0
5. Dead Grey Sand	12	0
6. Flints	1	0
7. Chalk	238	0
8. Grey Chalk	20	6
	294	6

The PRESIDENT said that no doubt the mottled clay, green sand, and sand-and-pebbles were Woolwich and Reading Beds, and the dead grey sand was Thanet Sand. What was described in the table as 'Grey Chalk' was probably Upper Chalk, the grey colour only being due to the fact that it was wet when first observed.

Prof. BOYD DAWKINS remarked that the 'dead grey sand' and the 'Grey Chalk' of the section were Thanet Sand and Upper Chalk. The section was a valuable addition to the literature of the water-supply from wells in the surrounding district.

The following communications were read :—

1. 'On some Effects of Earth-movement on the Carboniferous Volcanic Rocks of the Isle of Man.' By G. W. Lamplugh, Esq., F.G.S., of H.M. Geological Survey. (Communicated by permission of the Director-General of the Geological Survey.)

2. 'The Zonal Classification of the Wenlock Shales of the Welsh Borderland.' By Miss Gertrude L. Elles. (Communicated by J. E. Marr, Esq., M.A., F.R.S., F.G.S.)

3. 'On an Intrusion of Diabase into Permo-Carboniferous Rocks at Frederick Henry Bay (Tasmania).' By T. Stephens, Esq., M.A., F.G.S.

The following specimens and sections were exhibited :—

Cores from and Section of a Well-boring in the Zoological Society's Gardens, exhibited by Dr. P. L. Sclater, M.A., F.R.S., F.G.S.

Rock-specimens and Microscope-sections, exhibited by G. W. Lamplugh, Esq., F.G.S., in illustration of his paper.

Specimens of Wenlock Graptolites, from the district of Builth

(Radnorshire), exhibited on behalf of Miss G. L. Elles by J. E. Marr, Esq., M.A., F.R.S., F.G.S.

Rock-specimens exhibited by T. Stephens, Esq., M.A., F.G.S., in illustration of his paper.

A Special General Meeting was held at 7.45 P.M., at which Lieut.-General C. A. McMahon, F.R.S., was elected a Member of Council, and Mr. H. W. Monckton, F.L.S., was elected a Vice-President, in the room of Dr. Henry Hicks, deceased.

January 10th, 1900.

W. Whitaker, B.A., F.R.S., President, in the Chair.

Thomas Henry Bailey, Esq., M.Inst.C.E., Gwylfa, Portland Road, Edgbaston, Birmingham; Arthur Lewis Hall, Esq., B.A., Caius College, Cambridge; and William Spencer, Esq., Southfields, Leicester, were elected Fellows of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year: Bedford McNeill, Esq., and F. W. Rudler, Esq.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On a Particular Form of Surface, the Result of Glacial and Subaerial Erosion, seen on Loch Lochy and Elsewhere.' By Dr. W. T. Blanford, F.R.S., Treas.G.S.

2. 'On the Geology of Northern Anglesey: Part II.' By C. A. Matley, Esq., B.Sc., F.G.S.

3. 'The Formation of Dendrites.' By A. Octavius Watkins, Esq., A.R.S.M., F.G.S.

The following specimens, etc. were exhibited:—

Lantern-slides of Photographs, exhibited by Dr. W. T. Blanford, F.R.S., Treas.G.S., in illustration of his paper.

Microscope-sections and Rock-specimens from Northern Anglesey, exhibited by C. A. Matley, Esq., B.Sc., F.G.S., in illustration of his paper.

Specimens illustrating the Formation of Dendrites, exhibited by A. O. Watkins, Esq., F.G.S., in illustration of his paper.

Sheet 155 (Solid & Drift) of the New Series 1-inch Geological Survey Map of England & Wales (Atherstone), by C. Fox-Strangways & W. W. Watts, 1899, presented by the Director-General of H.M. Geological Survey.

January 24th, 1900.

W. Whitaker, B.A., F.R.S., President, in the Chair.

Wallace Broad, Esq., B.A., Bulawayo (Rhodesia); and Frank Raw, Esq., B.Sc., Lecturer and Demonstrator in Geology, Mason University College, Birmingham, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Fossils in the Oxford University Museum: II.—On Two New Genera and Species of Crinoidea.' By Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S., V.P.G.S.

2. 'Fossils in the Oxford University Museum: III.—A New Worm-track from the Slates of Bray Head (Ireland); with Observations on the Genus *Oldhamia*.' By Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S., V.P.G.S.

3. 'Contributions to the Geology of British East Africa: Part II.—The Geology of Mount Kenya.' By Prof. J. W. Gregory, D.Sc., F.G.S.

4. 'Contributions to the Geology of British East Africa: Part III.—The Nepheline-Syenite and Camptonitic Dykes intrusive in the Coast Series.' By Prof. J. W. Gregory, D.Sc., F.G.S.

The following specimens were exhibited:—

Specimens of two New Genera of Palæozoic Crinoids and Lantern-slides of the same; and Specimens, Microscope-sections, and Lantern-slides of *Oldhamia* and *Oldhamia*-bearing Rocks, exhibited by Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S., V.P.G.S., in illustration of his two papers.

February 7th, 1900.

W. Whitaker, B.A., F.R.S., President, in the Chair.

Ludwig Glauert, Esq., 21 Kenwood Park Road, Sheffield; and Kishen Singh, Bassali, Rawal Pindi District (Panjâb), India, were elected Fellows of the Society.

The List of Donations to the Library was read.

Prof. T. W. Edgeworth David, B.A., F.G.S., in exhibiting three small glacially-striated boulders from the Hunter River District (New South Wales), remarked that they were all obtained *in situ*. One was discovered by Mr. W. G. Woolnough in the Upper Marine beds of the Permo-Carboniferous rocks at Branxton, and the other two are samples of a large number found, by Mr. E. C. Andrews and Mr. O. Trickett, of the New South Wales Geological Survey, and the exhibitor, near Lochinvar in that colony. The horizon from which these recently-discovered striated pebbles were collected is probably not less than from 3500 to 4000 feet stratigraphically below that in which occur the upper boulder-beds, wherein Mr. R. D. Oldham had previously recorded the occurrence of a striated pebble. Both glacial horizons are intimately associated with marine Permo-Carboniferous beds, and they are separated one from the other by the Greta Coal Measures (containing *Glossopteris* abundantly), as well as by about 4000 feet of marine Permo-Carboniferous strata.

The following communications were read:—

1. 'Foraminifera from an Upper Cambrian Horizon in the Malverns.' By Frederick Chapman, Esq., A.L.S., F.R.M.S. (Communicated by Prof. T. T. Groom, M.A., D.Sc., F.G.S.)

2. 'Bala Lake and the River-System of North Wales.' By Philip Lake, Esq., M.A., F.G.S.

The following specimens, maps, etc., were exhibited, in addition to those mentioned above:—

Specimens and Lantern-slides of Cambrian Foraminifera from the Malvern Hills, exhibited in illustration of the paper by F. Chapman, Esq., A.L.S., F.R.M.S.

A Relief Map of Part of the Peak District and a Hypsometric Map of the Birmingham District, exhibited by Prof. C. Lapworth, LL.D., F.R.S., F.G.S.

Geological Survey of England & Wales: 1-inch Geological Map—new series, Sheet 339 (Teignmouth), by H. B. Woodward, W. A. E. Ussher, & C. Reid, 1899. Presented by the Director-General of H.M. Geological Survey.

Geological Map of South Australia, on the scale of 16 miles to the inch, by H. Y. L. Brown, 1899. Presented by the Author.

Twenty Platinotype Photographs of Fellows of the Society, cabinet size, presented by Messrs. Maull & Fox.

ANNUAL GENERAL MEETING,

February 16th, 1900.

W. Whitaker, B.A., F.R.S., President, in the Chair.

Report of the Council for 1899.

The upward tendency in the number of Fellows and the financial prosperity of the Society, which it has been the pleasant duty of the Council to record in many successive annual reports, were steadily maintained during 1899. So far the state of public affairs does not appear to have reacted, to any noticeable extent, upon the sources from which the Society derives its income.

During the past twelve months 52 Fellows were elected into the Society (exactly the same number as in 1898), of whom 45 paid their Admission Fees before the end of the year. Moreover, 11 Fellows, who had been elected in the previous year paid their Admission Fees in 1899, the total accession of new Fellows during the year under review amounting, therefore, to 56.

On the other hand, there was a total loss of 51 Fellows during the past twelve months—25 by death, 17 by resignation, and 9 by removal from the List because of non-payment of their Annual Contributions.

From the foregoing statistics it will be seen that the actual increase in the number of Fellows is 5.

Of the 25 Fellows deceased, 7 had compounded for their Annual Contributions, 14 were Contributing Fellows, and 4 were Non-Contributing Fellows. On the other hand, 4 Fellows during the year became Compounders.

The total accession of Contributing Fellows is thus seen to be 52 $(56-4)$, and the total loss being 40 $(14+17+9)$, the increase in the number of Contributing Fellows during 1899 is 12, as compared with an increase of 13 in 1898.

Turning now to the Lists of Foreign Members and Foreign Correspondents, it may be remembered that, at the end of 1898,

there were 3 vacancies in the List of Foreign Members and 1 in the List of Foreign Correspondents. During the past twelve months the Society has had to lament the loss by death of 3 of its Foreign Members and 2 of its Foreign Correspondents. The vacancies thus caused were in part filled by the election of 6 Foreign Members and 8 Foreign Correspondents, but at the end of the year 1899 there was still 1 vacancy in the List of Foreign Correspondents.

The total number of Fellows, Foreign Members, and Foreign Correspondents, which stood at 1336 on December 31st, 1898, had increased to 1344 by the end of 1899.

Proceeding now to consider the Income and Expenditure of the Society during the past year, the figures set forth in detail in the accompanying Balance-sheet may be summarized as follows:—

The total Receipts, including the Balance of £1076 0*s.* 8*d.* brought forward from the previous year, amounted to £3991 14*s.* 4*d.*, being £165 3*s.* 8*d.* more than the estimated Income.

On the other hand, the total Expenditure during 1899 (omitting the sum of £541 6*s.* 0*d.* invested in India 3 per cent. Stock), amounted to £3029 14*s.* 6*d.*, being £143 10*s.* 6*d.* more than the estimated Expenditure for the year. It will be borne in mind also that two items of non-recurring Expenditure are included in the above-mentioned total of £3029 14*s.* 6*d.*, namely, the sum of £73 16*s.* 5*d.*, expended in the publication of Vol. III. of Hutton's 'Theory of the Earth;' and the sum of £200 contributed by the Society, at the request of H.M. Office of Works, towards the cost of the improved lavatory accommodation at the Society's Apartments.[1]

The Balance remaining available for the current year is £420 13*s.* 10*d.*

The proposed Redecoration of the Society's Apartments, postponed in consequence of the laying-down of the new system of drainage and the structural alterations to which reference has been made, will be necessarily postponed again this year, as the completion of the work of extending the Electric Lighting to the whole of the Society's Apartments (which appears to the Council to be desirable) before proceeding to Redecoration, commends itself as the most economical course. A Committee nominated by the Council have considered the question of the Electric Lighting, in consultation with Mr. Musgrave Heaphy, C.E., F.G.S., who has once again placed his great professional knowledge and experience at the disposal of the Society, and it is estimated that the proposed extension can be carried out in a thoroughly satisfactory manner at a cost of about £250. To this expenditure the sanction of the Fellows is hereby requested.

At the Ordinary Meeting of November 4th, 1896, the then President announced that the late Sir Joseph Prestwich had bequeathed to this Society the sum of £800, for certain specific purposes, the legacy being payable after the decease of Lady Prestwich. In consequence of the lamented death of that lady,

[[1] This sum has now been repaid to the Society by H.M. Treasury.]

the legacy now falls due, but an intimation has been received from the executors that, in common with the other legacies, that to the Society will have to be, to some extent, abated, and, moreover, will have to bear its own legacy-duty.[1] The Fellows will learn with interest precisely in what terms Sir Joseph Prestwich expressed himself regarding this generous bequest. The following is a certified extract from his will:—

'(1) The sum of Eight Hundred Pounds to the Geological Society of London 'Upon Trust to invest the same in any of the Government securities and to apply 'the accumulated Annual Proceeds thereof at the end of every Three Years in 'providing a Gold Medal of the value of Twenty Pounds which with a purse 'containing the remainder of the said accumulated proceeds is to be awarded at the 'end of every Three Years to the person or persons either male or female and 'either resident in England or abroad who shall in the opinion of the said Society 'have done well for the Advancement of the Science of Geology or it shall be lawful 'for the said Society if in their opinion it shall be expedient so to do from time to 'time to accumulate the said Annual Proceeds for a period not exceeding Six Years 'and apply the said accumulated Annual Proceeds to some object of special research 'bearing on Stratigraphical or Physical Geology to be carried out by one single 'individual or by a Committee or failing these objects the said Society may accumulate 'the said Annual Proceeds for either Three or Six Years as the Council may decide 'and devote such proceeds to such special purposes as the Society may decide.'

The Third Volume of Hutton's 'Theory of the Earth,' printed from a previously unpublished manuscript in the possession of the Society, was issued in May last. The Council are of opinion that the Fellows owe a deep debt of gratitude to Sir Archibald Geikie for the minute and reverent care with which he has edited and annotated this long-neglected Volume. Moreover, he has supplemented it by an invaluable Index to the whole of the Three Volumes of Hutton's classic work. In accordance with the Estimate submitted last year, 500 copies were printed, and of these about 150 have been sold.

The Council have pleasure in announcing the completion of Vol. LV of the Society's Quarterly Journal, and the commencement of Vol. LVI. It will be seen that the expenditure upon the Journal exceeded the estimate by £146 7*s.* 11*d.* The Volume for 1899, however, considerably exceeded those published recently in the number both of pages and of illustrations, and the Council feel assured that the Fellows will concur in the opinion that the great scientific value of the many important papers which Vol. LV contains amply justifies the expenditure incurred in connexion with them.

In view of the report of the Catalogue Committee appointed by the Council, it has been decided to discontinue for the present the issue of Index-Slips with the Quarterly Journal.

The Record of Geological Literature issued by the Society appears to give continued satisfaction, and after careful study of possible alterations in its mode of issue, the Catalogue Committee, to whom the question was referred, have recommended that no change be

[[1] Since the Annual Meeting, the sum of £517 14*s.* 3*d.* has been paid to the Society by the executors.]

made in the present form of the Society's Record of Geological Literature.

In consequence of the lamented decease of Dr. Henry Hicks, one of your Vice-Presidents, a Special General Meeting was held on December 20th, 1899, at which Lieut.-Gen. C. A. McMahon was elected a Member of Council, and Mr. H. W. Monckton a Vice-President, in the room of the late Dr. Hicks.

The following Awards of Medals and Funds have been made by the Council:—

The Wollaston Medal is awarded to Prof. Grove Karl Gilbert, F.M.G.S., in recognition of the value of his researches concerning the mineral structure of the earth, and, more particularly, of his important contributions to Physical Geology, and especially to the Geological History of the American Continent.

The Murchison Medal and a sum of Ten Guineas from the Murchison Geological Fund are awarded to Baron Adolf Erik Nordenskiöld, F.M.G.S., in recognition of his valuable researches in Mineralogy, and more especially of his numerous arduous expeditions in the Arctic Regions, which have resulted in great and important additions to Geological and Geographical knowledge.

The Lyell Medal and a sum of Fifty Pounds from the Lyell Geological Fund are awarded to Mr. John Edward Marr, F.R.S., in recognition of the value of his services to Geological Science in general, and more particularly of his contributions towards the elucidation of the Stratigraphy and Physical Geology of the English Lake-District.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. George Thurland Prior, in recognition of his services to Mineralogy, and to encourage him in further research.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. Alfred Vaughan Jennings, in recognition of his researches in Petrology and Physical Geology, especially in the region around Davos (Engadin), and to encourage him in further work.

The Balance of the Proceeds of the Lyell Geological Fund, supplemented by a portion of the Proceeds of the Barlow-Jameson Fund, is awarded to Miss Gertrude L. Elles, as an acknowledgment of the value of her contributions to the study of the Graptolites and the rocks in which they occur, and to encourage her in further research.

A sum of Twenty Guineas, from the Proceeds of the Barlow-Jameson Fund, is awarded to Mr. George C. Crick, in recognition of the value of his contributions to the study of the Fossil Cephalopoda, and to assist him in further work.

A sum of Twenty Guineas, from the Proceeds of the Barlow-Jameson Fund, is awarded to Prof. Theodore Thomas Groom, in recognition of the value of his work in unravelling the complicated structure of the Malvern District, and to assist him in further research.

Report of the Library and Museum Committee for 1899.

Your Committee have pleasure in stating that the Additions made to the Library during the past twelve months were greater in number and by no means less in interest than the acquisitions of previous years. It is noticeable that, since the publication in its present form of the List of Geological Literature added to the Society's Library, foreign authors especially have shown themselves increasingly generous in the matter of presentation of copies of their works to this Society.

During 1899 the Library received by Donation 144 Volumes of separately published Works, 468 Pamphlets and detached Parts of Works, 228 Volumes and 109 detached Parts of Serial Publications (Transactions, Memoirs, Proceedings, etc.), and 16 Volumes of Newspapers.

The total number of accessions to the Library by Donation is thus seen to amount to 388 Volumes, 468 Pamphlets, and 109 detached Parts.

The number of Maps presented by various Donors is the largest recorded for a great many years, amounting to no less than 229 Sheets of Maps.

Although it is somewhat difficult to make a selection from among the numerous gifts of which statistics have been supplied in the foregoing paragraphs, your Committee may perhaps be allowed to draw attention to the following: 'The Life & Letters of Sir Joseph Prestwich' and Eight Volumes of his Lectures, Addresses, etc. presented by the late Lady Prestwich; Prof. K. A. von Zittel's 'History of Geology & Palæontology'; Messrs. Peach, Horne, & Teall's Geological Survey Memoir of the Silurian Rocks of Scotland; Prof. Fritsch's monograph on the Younger Palæozoic Arachnoidea of Bohemia; Dr. W. Waagen & Prof. J. Jahn's monograph on the Silurian Crinoidea of the same country; Messrs. Hall & Clarke's monograph on the Palæozoic Reticulate Sponges of New York; Mr. Strahan's Geological Survey Memoir of the Isle of Purbeck & Weymouth; the Annual Reports (1896–1898) and Monographs of the United States Geological Survey; and those of the Kansas and Iowa Geological Surveys. A collection of 69 Pamphlets was presented by Mr. George Clinch.

Turning from Books to Maps, the following Donations are especially noteworthy: the splendid Atlas of Finland, published by the Geographical Society of that Duchy; 7 Sheets of the International Geological Map of Europe; Victor Raulin's Geological and Agronomic Maps of the Landes, in 3 Sheets; the General Geological Map of the Austrian Empire, in 10 Sheets; the Official Map of the Distribution of Useful Minerals in Hungary; 31 Sheets of the Geological Survey maps of Rumania, Sweden, South Australia, Western Australia, and Queensland; and 28 Sheets of Maps of the Geological Surveys of the United Kingdom.

The Books and Maps enumerated above were the gift of 179

Personal Donors; 95 Government Departments and other Public Bodies; and 157 Societies and Editors of Periodicals.

The Purchases made on the recommendation of the standing Library Committee comprised 68 Volumes and 24 Parts of separately published Works; 42 Volumes and 14 Parts of works published serially; and 21 Sheets of Maps.

The total Expenditure incurred in connexion with the Library during the past twelve months was as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased..........	67	1	6
Binding of Books and Mounting of Maps....	180	17	8
	£247	19	2

The Society's Collection of Portraits of eminent Geologists has been enriched by the Donation by Dr. H. C. Sorby, F.R.S., of an Autotype copy of a Portrait of himself; and a Portrait-group of Fellows of the Geological Society of America, presented by Mr. John Eyerman.

Museum.

No addition has been made to the collections during the past year. Mr. C. Davies Sherborn was able, early in the year, to announce that he had completed the work of labelling and registering the type- and other important specimens in the Foreign Collection; and the total Expenditure incurred in connexion with the Museum during 1899 was as follows:—

	£	s.	d.
Special work (registration, etc.)	11	8	0
Sundries............................	1	4	0
	£12	12	0

The question of the custody and utilization of the type- and other important specimens having been referred to your Committee, they reported on June 21st, 1899, 'That everyone, whether a Fellow or 'otherwise, examining any portion of the collections, be required 'to sign a register stating the numbers of the drawers examined 'and the purpose of the examination.'

The foregoing resolution, having been adopted by the Council, is now strictly enforced.

The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review :—

I. Government Departments and other Public Bodies.

Alabama Geological Survey. Montgomery.
American Museum of Natural History. New York.
Athens.—Observatoire national d'Athènes.
Australian Museum. Sydney.
Austria.—Kaiserlich-königliche Geologische Reichsanstalt. Vienna.
——. Kaiserlich-königliches Naturhistorisches Hofmuseum. Vienna.
Bavaria.—Königlich Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique. Brussels.
Berlin.—Königliche Preussische Akademie der Wissenschaften.
Birmingham.—Mason University College.
Bohemia.—Musée d'Histoire naturelle. Prague.
British South Africa Company. London.
Buenos Aires.—Museo Nacional.
California.—State Mining Bureau. San Francisco.
California University. Berkeley.
Cambridge (Mass.).—Museum of Comparative Zoology, Harvard College.
Canada.—Geological and Natural History Survey. Ottawa.
Cape Colony.—Department of Agriculture, Geological Commission. Cape Town.
Chicago.—'Field' Columbian Museum.
Coolgardie.—Chamber of Mines.
Denmark.—Danmarks geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Europe.—Commission Géologique Internationale. Berlin & St. Petersburg.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Dépôt de la Marine. Paris.
——. Ministère des Travaux Publics. Paris.
——. Muséum d'Histoire Naturelle. Paris.
Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle.
Great Britain.—Army Medical Department. London.
——. British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. Ordnance Survey. Southampton.
Holland.—Departement van Kolonien. The Hague.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Fõldtani Tarsulat). Budapest.
India.—Geological Survey. Calcutta.
——. Indian Museum. Calcutta.
Iowa.—Geological Survey. Des Moines.
Italy.—Reale Comitato Geologico. Rome.
Kansas.—University Geological Survey. Topeka.
Kingston (Canada).—Queen's College.
La Plata Museum. La Plata.
London.—City of London College.
——. Royal College of Surgeons.
——. University College.
Madrid.—Real Academia de Ciencias exactas, fisicas y naturales.
Maryland Geological Survey. Baltimore.
Mexico.—Instituto Geologico. Mexico City.
Michigan College of Mines. Houghton.
Milwaukee.—Public Museum of the City of Milwaukee.
Munich.—Königliche Bayerische Akademie der Wissenschaften.

New South Wales.—Agent-General for, London.
——. Department of Lands. Sydney.
——. Department of Mines and Agriculture. Sydney.
——. Geological Survey. Sydney.
New York Museum. Albany.
New Zealand.—Department of Mines. Wellington.
——. Educational Department. Wellington.
Norway.—Meteorological Department. Christiania.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Pisa.—Royal University.
Portugal.—Commissão Geologica. Lisbon.
Prussia.—Ministerium für Handel und Gewerbe. Berlin.
Queensland.—Agent General for, London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Rome.—Reale Accademia dei Lincei.
Rumania.—Museum of Geology and Palæontology. Bucharest.
Russia.—Comité Géologique. St. Petersburg.
——. Section géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
São Paulo.—Commissão geographica e geologica de São Paulo.
South Australia.—Agent-General for, London.
——. Government Geologist. Adelaide.
Spain.—Comision del Mapa Geológico. Madrid.
St. Petersburg.—Académie Impériale des Sciences.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Commission géologique. Berne.
Tokio.—Imperial University.
——. College of Science.
Turin.—Reale Accademia delle Scienze.
United States.—Geological Survey. Washington.
——. Department of Agriculture. Washington.
——. National Museum. Washington.
Upsala University.
—— ——. Mineralogical and Geological Institute.
Vienna.—Kaiserliche Akademie der Wissenschaften.
Washington (D.C.).—Smithsonian Institution.
West Virginia.—Geological Survey. Morgantown.
Western Australia.—Agent-General for, London.
——. Department of Mines. Perth.
——. Geological Survey. Perth.

II. Societies and Editors.

Adelaide.—Royal Society of South Australia.
Agram.—Societas Historico-naturalis Croatica.
Alnwick.—Berwickshire Naturalists' Club.
Auckland.—New Zealand Institute of Mining Engineers.
Bahia.—Instituto Geographico e Historico.
Barnsley.—Midland Institute of Mining, Civil, and Mechanical Engineers.
Bath.—Natural History and Antiquarian Field Club.
Belfast Natural History and Philosophical Society.
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. Zeitschrift für Praktische Geologie.
Berne.—Schweizerische Naturforschende Gesellschaft.
Bombay Branch of the Royal Asiatic Society.
Boston (Mass.).—American Academy of Arts and Sciences.
Boston Society of Natural History.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société Belge de Géologie, de Paléontologie et d'Hydrologie.
——. Société Malacologique de Belgique.
Budapest.—Földtani Közlöny (Geological Magazine).

Buenos Aires.—Instituto Geografico Argentino.
——. Sociedad Científica Argentina.
Calcutta.—Indian Engineering.
——. Asiatic Society of Bengal.
Cape Town.—South African Philosophical Society.
Cardiff.—South Wales Institute of Engineers.
Chicago.—Academy of Sciences.
——. Journal of Geology.
Cincinnati Society of Natural History.
Colombo.—Ceylon Branch of the Royal Asiatic Society.
Colorado Springs.—Colorado College Studies.
Copenhagen.—Dansk Geologisk Forening.
Córdoba (Argentine Republic).—Academia Nacional de Ciencias.
Cracow.—Académie des Sciences (Akademja Umiejetosci).
Darmstadt.—Verein für Erdkunde.
Dorpat.—Naturforschende Gesellschaft.
Douglas.—Isle of Man Natural History and Antiquarian Society.
Dresden.—Naturwissenschaftliche Gesellschaft 'Isis.'
Dublin.—Royal Dublin Society.
Edinburgh.—Geological Society.
——. Royal Physical Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Frankfurt a. M.—Senckenbergische Naturforschende Gesellschaft.
Freiburg i. B.—Naturforschende Gesellschaft.
Geneva.—Société Physique et d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- und Heilkunde.
Haarlem.—Société Hollandaise des Sciences.
Halifax.—Yorkshire Geological and Polytechnic Society.
—— (N. S.).—Nova Scotian Institute of Science.
Hamilton (Canada).—Hamilton Association.
Hanau.—Wetterauische Gesellschaft für gesammte Naturkunde.
Helsingfors.—Geografiska Förening i Finland.
Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaften.
Hertford.—Hertfordshire Natural History Society.
Johannesburg.—Geological Society of South Africa.
Lausanne.—Société Vaudoise des Sciences Naturelles.
Lawrence.—Kansas University Quarterly.
Leicester.—Literary and Philosophical Society.
Leipzig.—Zeitschrift für Krystallographie und Mineralogie.
——. Zeitschrift für Naturwissenschaften.
Liége.—Société Géologique de Belgique.
Lille.—Société Géologique du Nord.
Lima.—Revista de Ciencias.
Lisbon.—Sociedade de Geographia.
Liverpool.—Geological Society.
London.—'Academy.'
——. 'Athenæum.'
——. British Association for the Advancement of Science.
——. 'Chemical News.'
——. Chemical Society.
——. 'Colliery Guardian.'
——. East India Association.
——. 'Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Iron and Steel Institute.
——. 'Iron and Steel Trades' Journal.'
——. 'Knowledge.'
——. Linnean Society.
——. 'London, Edinburgh, and Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'Nature.'
——. Palæontographical Society.
——. 'Quarry.'

London.—Ray Society.
——. Royal Agricultural Society.
——. Royal Astronomical Society.
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society of Great Britain.
——. Royal Society.
——. Society of Arts.
——. Society of Biblical Archæology.
——. Society of Public Analysts.
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Madison.—Wisconsin Academy of Sciences.
Manchester.—Geological Society.
——. Literary and Philosophical Society.
Mexico.—Sociedad científica 'Antonio Alzate.'
Milan.—Reale Istituto Lombardo di Scienze e Lettere.
Montreal.—Natural History Society.
Moscow.—Société Impériale des Naturalistes.
New Haven (Conn.).—American Journal of Science.
——. Connecticut Academy of Sciences.
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
Newcastle-upon-Tyne.—North of England Institute of Mining and Mechanical Engineers.
Northampton.—Northamptonshire Natural History Society.
Nürnberg.—Naturhistorische Gesellschaft.
Ottawa.—Royal Society of Canada.
Padua.—Reale Accademia di Scienze, Lettere ed Arti.
Palermo.—Annales de Géologie et de Paléontologie.
Paris.—Revue Scientifique.
——. Société Française de Minéralogie.
——. Société Géologique de France.
——. 'Spelunca.'
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
——. Wagner Free Institute of Science.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Rochester (N.Y.).—Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Salem (Mass.).—Essex Institute.
Santiago de Chile.—Deutscher wissenschaftlicher Verein.
——. Sociedad Nacional de Mineria.
——. Société Scientifique du Chili.
Scranton (Pa.).—'Mines and Minerals.'
Shanghai.—China Branch of the Royal Asiatic Society.
St. John.—Natural History Society of New Brunswick.
St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.
Stockholm.—Geologiska Förening.
Stuttgart.—Neues Jahrbuch für Mineralogie, Geologie und Paläontologie.
——. Verein für Vaterländische Naturkunde in Württemberg.
——. Zeitschrift für Naturwissenschaften.
Sydney.—Australasian Association for the Advancement of Science.
——. Australasian Institute of Mining Engineers.
——. Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Truro.—Royal Institution of Cornwall.
Vienna.—Berg- und Hüttenmännisches Jahrbuch.

Vienna.—Kaiserlich-königliche Zoologisch-botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Biological Society.
Wellington (N.Z.).—New Zealand Institute.
Wiesbaden.—Nassauischer Verein für Naturkunde.
York.—Yorkshire Philosophical Society.

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Wilkinson, W. F.
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Woodward, H.
Woodward, H. B.
Worth, R. H.

Zeiller, R.
Zittel, K. A. von.

Comparative Statement of the Number of the Society at the Close of the Years 1898 and 1899.

	Dec. 31st, 1898.		Dec. 31st, 1899.
Compounders	291	......	288
Contributing Fellows	911	......	923
Non-contributing Fellows	58	......	54
	1260		1265
Foreign Members	37	......	40
Foreign Correspondents	39	......	39
	1336		1344

Comparative Statement explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1898 *and* 1899.

Number of Compounders, Contributing and Non-contributing Fellows, December 31st, 1898 ..			1260
Add Fellows elected during the former year and paid in 1899			11
Add Fellows elected and paid in 1899			45
			1316
Deduct Compounders deceased................		7	
Contributing Fellows deceased		14	
Non-contributing Fellows deceased		4	
Contributing Fellows resigned		17	
Contributing Fellows removed		9	
		—	51
			1265
Number of Foreign Members and Foreign Correspondents, December 31st, 1898		76	
Deduct Foreign Members deceased	3		
Foreign Correspondents deceased ..	2		
Foreign Correspondents elected Foreign Members	6		
	—	11	
		65	
Add Foreign Members elected	6		
Foreign Correspondents elected	8		
	—	14	
		—	79
			1344

Deceased Fellows.

Compounders (7).

Dowker, G., Esq.
Eskrigge, R. A., Esq.
Flower, Sir William.
Galton, Sir Douglas.
Garland, J., Esq.
Hall, T. M., Esq.
Redman, J. B., Esq.

Resident and other Contributing Fellows (14).

Bailey, S., Esq.
Baker, W. J., Esq.
Brooke, E., Esq.
Brothers, H., Esq.
Campbell, W. Y., Esq.
Cooke, Prof. S.
Hawley, T. G., Esq.
Hicks, Dr. H.
Hylton, Lord.
Mott, A. J., Esq.
Nicholson, Prof. H. A.
Scott, Maj.-Gen. A. de C.
Seal, S., Esq.
Webb, W. F.

Non-contributing Fellows (4).

Dawson, Sir J. William.
M'Coy, Sir Frederick.
Reid, Capt. J. H.
Roosmalecoeq, A. H., Esq.

Foreign Members (3).

Bunsen, Prof. R. W.
Hauer, F. Ritter von.
Marsh, Prof. O. C.

Foreign Correspondents (2).

Brongniart, Dr. C.
Lartet, Prof. L.

Fellows Resigned (17).

Balfour, Prof. I. B.
Brooks, Maj. T. B.
Croix, J. E. de la, Esq.
Freeman, G. A., Esq.
Hawkins, S. J., Esq.
Hichens, J. H., Esq.
Irving, Rev. A.
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Niven, G., Esq.
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FELLOWS REMOVED (9).

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Farnfield, S., Esq.
Hawkins, Rev. C. F. B.
Hurst, H. E., Esq.
Ross, Dr. J. C.
Spark, H. K., Esq.
Tapscott, R. L., Esq.
White, A. H. S., Esq.

The following Personages were elected Foreign Members during the year 1899:—

Prof. Marcel Bertrand, of Paris.
M. Ernest Van den Broeck, of Brussels.
Senhor J. F. N. Delgado, of Lisbon.
Prof. Alphonse Milne-Edwards, of Paris.
Prof. Emmanuel Kayser, of Marburg.
Dr. Charles Abiathar White, of Washington, D.C. (U.S.A.).

The following Personages were elected Foreign Correspondents during the year 1899:—

Prof. C. E. Beecher, of New Haven, Conn. (U.S.A.).
Dr. Gerhard Holm, of Stockholm.
Prof. Th. Liebisch, of Göttingen.
Prof. Franz Lœwinson-Lessing, of Dorpat.
M. Michel F. Mourlon, of Brussels.
Prof. Henry Fairfield Osborn, of New York (U.S.A.).
Prof. Gregorio Stefanescu, of Bucharest.
Prof. René Zeiller, of Paris.

After the Reports had been read, it was resolved:—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved:—

That the thanks of the Society be given to W. Whitaker, Esq., retiring from the office of President.

That the thanks of the Society be given to the Rev. H. H. Winwood, retiring from the office of Vice-President.

That the thanks of the Society be given to Dr. J. W. Gregory, Dr. G. J. Hinde, W. H. Hudleston, Esq., A. C. Seward, Esq., and A. Strahan, Esq., retiring from the Council.

After the Balloting-glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

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TREASURER.

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LIST OF

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Date of Election.

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1857. Prof. H. B. Geinitz, *Dresden.* (*Deceased.*)
1871. Dr. Franz Ritter von Hauer, *Vienna.* (*Deceased.*)
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1883. Prof. Otto Martin Torell, *Stockholm.*
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1889. Prof. Ferdinand Fouqué, *Paris.*
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1898. Geheimrath Prof. Hermann Credner, *Leipzig.*
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1874.	Prof. Igino Cocchi, *Florence.*
1879.	Dr. Émile Sauvage, *Boulogne-sur-Mer.*
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1898.	Dr. W. H. Dall, *Washington, D.C., U.S.A.*
1898.	M. A. Karpinsky, *St. Petersburg.*
1899.	Prof. Charles Emerson Beecher, *New Haven, U.S.A.*
1899.	Dr. Gerhard Holm, *Stockholm.*
1899.	Prof. Th. Liebisch, *Göttingen.*
1899.	Prof. Franz Lœwinson-Lessing, *Dorpat.*
1899.	M. Michel F. Mourlon, *Brussels.*
1899.	Prof. Henry Fairfield Osborn, *New York, U.S.A.*
1899.	Prof. Gregorio Stefanescu, *Bucharest.*
1899.	Prof. René Zeiller, *Paris.*

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

'To promote researches concerning the mineral structure of the earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1831. Mr. William Smith.
1835. Dr. G. A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. H. Falconer.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Prof. A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron L. von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy.
1844. Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir Henry De la Beche.
1856. Sir William Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Mr. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Prof. Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Prof. Gustav Bischof.
1864. Sir Roderick Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Prof. Carl F. Naumann.
1869. Dr. H. C. Sorby.
1870. Prof. G. P. Deshayes.
1871. Sir Andrew Ramsay.
1872. Prof. James D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Prof. Oswald Heer.
1875. Prof. L. G. de Koninck.
1876. Prof. T. H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Prof. Bernhard Stüder.
1880. Prof. Auguste Daubrée.
1881. Prof. P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. W. T. Blanford.
1884. Prof. Albert Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Des Cloizeaux.
1887. Mr. J. Whitaker Hulke.
1888. Mr. H. B. Medlicott.
1889. Prof. T. G. Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John W. Judd.
1892. Baron Ferdinand von Richthofen.
1893. Prof. N. S. Maskelyne.
1894. Prof. Karl Alfred von Zittel.
1895. Sir Archibald Geikie.
1896. Prof. Eduard Suess.
1897. Mr. W. H. Hudleston.
1898. Prof. Ferdinand Zirkel.
1899. Prof. Charles Lapworth.
1900. Prof. Grove K. Gilbert.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. G. A. Mantell.
1836. Prof. G. P. Deshayes.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Prof. Edward Forbes.
1842. Prof. John Morris.
1843. Prof. John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape-of-Good-Hope Fossils. M. Alcide d'Orbigny. }
1849. Mr. William Lonsdale.
1850. Prof. John Morris.
1851. M. Joachim Barrande.
1852. Prof. John Morris.
1853. Prof. L. G. de Koninck.
1854. Dr. S. P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Prof. G. P. Deshayes.
1857. Dr. S. P. Woodward.
1858. Prof. James Hall.
1859. Mr. Charles Peach.
1860. { Prof. T. Rupert Jones. Mr. W. K. Parker. }
1861. Prof. Auguste Daubrée.
1862. Prof. Oswald Heer.
1863. Prof. Ferdinand Senft.
1864. Prof. G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Mr. William Carruthers.
1870. M. Marie Rouault.
1871. Mr. Robert Etheridge.
1872. Dr. James Croll.
1873. Prof. J. W. Judd.
1874. Dr. Henri Nyst.
1875. Prof. L. C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. R. Etheridge, Jun.
1878. Prof. W. J. Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. R. H. Traquair.
1882. Dr. George J. Hinde.
1883. Prof. John Milne.
1884. Mr. E. Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Mr. B. N. Peach.
1888. Mr. John Horne.
1889. Dr. A. Smith Woodward.
1890. Mr. W. A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville A. Derby.
1893. Mr. J. G. Goodchild.
1894. Mr. Aubrey Strahan.
1895. Prof. W. W. Watts.
1896. Mr. Alfred Harker.
1897. Mr. F. A. Bather.
1898. Mr. E. J. Garwood.
1899. Prof. J. B. Harrison.
1900. Mr. George T. Prior.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

'To be applied in every consecutive year in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1873. Mr. William Davies.
1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
1876. Mr. Alfred R. C. Selwyn.
1877. Rev. W. B. Clarke.
1878. Prof. Hanns B. Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. Rev. P. B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. W. C. Brögger.
1892. Prof. A. H. Green.
1893. Rev. Osmond Fisher.
1894. Mr. W. T. Aveline.
1895. Prof. Gustav Lindström.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. T. F. Jamieson.
1899. { Mr. B. N. Peach. / Mr. John Horne.
1900. Baron A. E. Nordenskiöld.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

1873. Prof. Oswald Heer.
1874. Mr. Alfred Bell.
1874. Prof. Ralph Tate.
1875. Prof. H. G. Seeley.
1876. Dr. James Croll.
1877. Rev. J. F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. J. W. Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. T. Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Mr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward Wethered.
1891. Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. G. J. Williams.
1894. Mr. George Barrow.
1895. Mr. A. C. Seward.
1896. Mr. Philip Lake.
1897. Mr. S. S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal 'to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions at the discretion of the Council for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

1876. Prof. John Morris.
1877. Sir James Hector.
1878. Mr. George Busk.
1879. Prof. Edmond Hébert.
1880. Sir John Evans.
1881. Sir J. William Dawson.
1882. Dr. J. Lycett.
1883. Dr. W. B. Carpenter.
1884. Dr. Joseph Leidy.
1885. Prof. H. G. Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. H. A. Nicholson.
1889. Prof. W. Boyd Dawkins.
1890. Prof. T. Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. E. T. Newton.
1894. Prof. John Milne.
1895. Rev. J. F. Blake.
1896. Dr. A. Smith Woodward.
1897. Dr. George J. Hinde.
1898. Prof. W. Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Mr. John Edward Marr.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. W. Waagen.
1879. Prof. H. A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Dr. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. E. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. A. J. Jukes-Browne.
1886. Mr. D. Mackintosh.
1887. Rev. Osmond Fisher.
1888. Mr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. M. Louis Dollo.
1890. Mr. C. Davies Sherborn.
1891. Dr. C. I. Forsyth-Major.
1891. Mr. G. W. Lamplugh.
1892. Dr. J. W. Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Mr. Percy F. Kendall.
1895. Mr. Benjamin Harrison.
1896. Dr. William F. Hume.
1896. Mr. Charles W. Andrews.
1897. Mr. W. J. Lewis Abbott.
1897. Mr. Joseph Lomas.
1898. Mr. William H. Shrubsole.
1898. Mr. Henry Woods.
1899. Mr. Frederick Chapman.
1899. Mr. John Ward.
1900. Miss Gertrude L. Elles.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

Dr. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgement of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1877. Prof. Othniel C. Marsh.
1879. Prof. Edward D. Cope.
1881. Dr. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Mr. J. J. Harris Teall.
1891. Dr. George M. Dawson.
1893. Prof. William J. Sollas.
1895. Mr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. Edgeworth David.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

Dr. H. C. BARLOW, F.G.S.

The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1879. Purchase of Microscope.
1881. Purchase of Microscope-lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Purchase of Scientific Instruments for Capt. F. E. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Prof. Theodore T. Groom.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				70	0	0
Due for Arrears of Admission Fees	44	2	0			
Admission Fees, 1900	207	18	0			
				252	0	0
Arrears of Annual Contributions	163	16	0			
Annual Contributions, 1900, from Resident Fellows, and Non-Residents, 1859 to 1861	1642	12	0			
Annual Contributions in advance	42	0	0			
				1848	8	0
Sale of Quarterly Journal, including Longmans' Account	150	0	0			
Sale of Transactions, Library Catalogue, General Index, Hutton's 'Theory of the Earth,' vol. iii, Hochstetter's 'New Zealand,' and List of Fellows	12	0	0			
				162	0	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	51	16	0			
				343	16	0
				2676	4	0
Balance against the Society				250	0	0
				£2926	4	0

Note.—The following Funds are available for Extraordinary Expenditure:—

	£	s.	d.
Balance in Bankers' hands at December 31st, 1899:			
On Current Account	146	5	10
On Deposit Account	250	0	0
Balance in Clerk's hands at December 31st, 1899	24	8	0
	£420	13	10

the Year 1900.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes		15	0			
Fire Insurance	15	0	0			
Electric Lighting	12	0	0			
Gas	18	0	0			
Fuel	30	0	0			
Furniture and Repairs	40	0	0			
House-repairs and Maintenance	40	0	0			
Annual Cleaning	15	0	0			
Washing and Sundries	35	0	0			
Tea at Meetings	20	0	0			
				225	15	0
Salaries and Wages, etc.:						
Assistant Secretary	300	0	0			
,, Half Premium of Life Insurance	10	15	0			
Assistant Librarian	150	0	0			
Assistant Clerk	110	0	0			
House Porter and Upper Housemaid	91	12	0			
Under Housemaid	42	12	0			
Errand Boy	40	0	0			
Charwoman and Occasional Assistance	10	0	0			
Accountant's Fee	10	10	0			
				765	9	0
Office Expenditure:						
Stationery	25	0	0			
Miscellaneous Printing	35	0	0			
Postage and Sundry Expenses	80	0	0			
				140	0	0
Library (Books and Binding)				250	0	0
Museum				20	0	0
Publications:						
Quarterly Journal, including Commission on Sale	900	0	0			
Record of Geological Literature	140	0	0			
List of Fellows	35	0	0			
Postage on Journal, Addressing, etc.	90	0	0			
Abstracts, including Postage	110	0	0			
				1275	0	0
Estimate of Ordinary Expenditure				2676	4	0
Cost of extension of the Electric Lighting in the Society's Apartments				250	0	0
				£2926	4	0

W. T. BLANFORD, *Treasurer.*

January 27th, 1900.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in Bankers' hands at January 1st, 1899:						
On Current Account	318	17	11			
On Deposit Account	750	0	0			
,, Balance in Clerk's hands at January 1st, 1899	7	2	9			
				1076	0	8
,, Compositions				120	4	6
,, Arrears of Admission Fees	69	6	0			
,, Admission Fees	277	4	0			
				346	10	0
,, Arrears of Annual Contributions	148	2	0			
,, Annual Contributions of 1899, namely:						
Resident Fellows	1700	1	0			
Non-Resident Fellows	16	3	6			
,, Annual Contributions in advance	46	4	0			
				1910	10	6
,, Taylor & Francis: Advertisements in Journal, No. 214				1	7	0
,, Publications:						
Sale of Journals, Vols. 1 to 54 *	91	6	0			
,, Journal, Vol. 55 *	65	0	10			
,, Geological Map	3	4	2			
,, Record of Geological Literature	1	5	6			
,, Library Catalogue		5	0			
,, List of Fellows		13	0			
,, Ormerod's Index		10	0			
,, General Index to Quarterly Journal		15	0			
,, Transactions	2	7	6			
,, Hutton's 'Theory of the Earth' (vol. iii)	17	10	10			
				182	17	10
,, Income Tax Repayment				11	1	8
,, Dividends (less Income Tax) on						
£2500 India 3 per cent. Stock	68	17	6			
£300 L. B. & S. C. Railway 5 p. c. Consol. Preference Stock	14	10	0			
£2250 L. & N. W. Railway 4 p. c. Preference Stock	87	0	0			
£2800 L. & S. W. Railway 4 p. c. Preference Stock	108	5	4			
£2072 Midland Railway 2½ p.c. Perpetual Preference Stock	50	1	6			
				328	14	4
,, Interest on Deposit				14	7	10
				£3991	14	4

*Due from Messrs. Longmans, in addition to the above, on Journal, Vol. 55, etc. £68 19 8

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

F. W. RUDLER,
BEDFORD McNEILL, } *Auditors.*

Year ended December 31st, 1899.

PAYMENTS.

	£ s. d.	£ s. d.
By House Expenditure:		
Taxes	15 0	
Fire Insurance	15 0 0	
Electric Lighting	10 9 6	
Gas	17 13 11	
Fuel	27 13 9	
Furniture and Repairs	27 19 8	
House-repairs and Maintenance	27 3 1	
Annual Cleaning	11 14 6	
Washing and Sundries	34 16 6	
Tea at Meetings	19 1 10	
		192 7 9
„ Salaries and Wages, etc.:		
Assistant Secretary	300 0 0	
„ Half Premium of Life Insurance	10 15 0	
Assistant Librarian	150 0 0	
Assistant Clerk	100 0 0	
House Porter and Upper Housemaid	90 4 0	
Under Housemaid	43 18 0	
Errand Boy	40 0 0	
Charwoman and Occasional Assistance	13 18 0	
Accountant's Fee	10 10 0	
Assistant Clerk: Allowance for Rooms during alterations	22 2 6	
		781 7 6
„ Office Expenditure:		
Stationery	33 11 2	
Miscellaneous Printing	34 1 8	
Postage and Sundry Expenses	74 2 3	
		141 15 1
„ Library		247 19 2
„ Museum		12 12 0
„ Publications:		
Journal, Vols. 1 to 54, Commission on sale thereof	8 3 8	
Journal, Vol. 55, Commission on sale thereof	5 4 5	
Paper, Printing, and Illustrations	996 7 11	
List of Fellows	36 9 6	
Record of Geological Literature	128 0 3	
Geological Map. Commission on sale thereof	2 2	
Postage and Addressing Journal, etc.	94 5 9	
Abstracts, including Postage	111 2 11	
Hutton's 'Theory of the Earth' (vol. iii)	73 16 5	
		1453 13 0
„ Contribution to new Lavatory accommodation		200 0 0
„ Purchase of £500 India 3 per cent. Stock		541 6 0
„ Balance in Bankers' hands at December 31st, 1899:		
On Current Account	146 5 10	
On Deposit Account	250 0 0	
„ Balance in Clerk's hands at December 31st, 1899	24 8 0	
		420 13 10
		£3991 14 4

W. T. BLANFORD, *Treasurer.*

January 27th, 1900.

Statement of Trust Funds: December 31st, 1899.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at Bankers' at January 1st, 1899	32	3	8	By Cost of striking Gold Medal awarded to Prof. C. Lapworth	10	10	0
„ Dividends (less Income Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	31	2	4	„ Award to Prof. J. B. Harrison	21	13	8
„ Repayment of one year's Income Tax	1	1	4	„ Balance at Bankers' at December 31st, 1899	32	3	8
	£64	7	4		£64	7	4

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at Bankers' at January 1st, 1899	20	13	6	By Award to Mr. B. N. Peach, with Medal	10	10	0
„ Dividends (less Income Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	38	13	8	„ „ Mr. J. Horne, with Medal	10	10	0
„ Repayment of one year's Income Tax	1	6	8	„ „ Mr. J. Bennie	17	6	4
				„ Cost of Medals	1	14	0
				„ Balance at Bankers' at December 31st, 1899	20	13	6
	£60	13	10		£60	13	10

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at Bankers' at January 1st, 1899	53	6	11	By Award to Lieut.-Gen. C. A. McMahon, with Medal	25	0	0
„ Dividends (less Income Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	68	0	4	„ „ Mr. F. Chapman	22	3	0
„ Repayment of one year's Income Tax	2	6	8	„ „ Mr. J. Ward	22	3	0
				„ Cost of Medal	1	1	0
				„ Balance at Bankers' at December 31st, 1899	53	6	11
	£123	13	11		£123	13	11

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at Bankers' at January 1st, 1899	28	2	6	By Award to Mr. J. Bennie	3	13	8
„ Dividends (less Income Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	13	11	6	„ Balance at Bankers' at December 31st, 1899	38	9	8
„ Repayment of one year's Income Tax		9	4				
	£42	3	4		£42	3	4

'Bigsby Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at Bankers' at January 1st, 1899	9	11	3	By Cost of Medal awarded to Prof. T. W. Edgeworth-David	12	12	2
„ Dividends (less Income Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	6	1	10	„ Balance at Bankers' at December 31st, 1899	3	5	1
„ Repayment of one year's Income Tax		4	2				
	£15	17	3		£15	17	3

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at Bankers' at January 1st, 1899	5	19	6	By Grants	4	4	0
„ Dividends (less Income Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	4	0	8	„ Balance at Bankers' at December 31st, 1899	5	18	10
„ Repayment of one year's Income Tax		2	8				
	£10	2	10		£10	2	10

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

W. T. BLANFORD, *Treasurer*.

F. W. RUDLER,
BEDFORD McNEILL, } *Auditors*.

Statement of the Society's Property: December 31st, 1899.

PROPERTY.	£	s.	d.
Due from Longmans & Co., on account of Journal, Vol. LV, etc.	68	19	8
Balance in Bankers' hands, Dec. 31st, 1899:			
On Current Account	146	5	10
On Deposit Account	250	0	0
Balance in Clerk's hands, Dec. 31st, 1899	24	8	0
Funded Property:—			
£2500 India 3 per cent. Stock	2623	6	0
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898	10	6
£2800 London & South-Western Railway 4 per cent. Preference Stock	3607	7	6
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502	15	3
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	1850	19	6
Arrears of Admission Fees	44	2	0
Arrears of Annual Contributions	163	16	0
	£12,180	10	3

[*N.B.—The above does not include the value of the Collections, Library, Furniture, and Stock of unsold Publications.*]

	£	s.	d.
Balance in favour of the Society	12,180	10	3
	£12,180	10	3

W. T. BLANFORD, *Treasurer.*

January 27th, 1900.

Note.—The investments in Stocks are valued at their cost price. An addition of £500 has been made to the amount of India 3 per cent. Stock during the past year.

Award of the Wollaston Medal.

In handing the Wollaston Medal, awarded to Prof. Grove Karl Gilbert, F.M.G.S., of Washington, to Mr. Henry White, Secretary of the American Embassy, for transmission to the recipient, the President addressed him as follows:—

Mr. White,—

For many years Prof. Gilbert has contributed to several American publications papers of a most varied kind, some dealing with important subjects appertaining to the Geology of the United States and some with matters of still wider interest.

The same may be said of his series of Reports, etc. to the Geological Survey of the United States, beginning with the well-known 'Geology of the Henry Mountains,' in which the volcanic structure known as a laccolite was first described, and a masterly summary of the principles of erosion was given. The Essay on the Topographical Features of Lake-shores, descriptive of the work of waves, of streams, and of ice, of the formation of deltas, of cliffs, and of terraces, naturally led up to the great monograph on Lake Bonneville, the tracing out of a former feature (whereof the present Great Salt Lake is the diminished representative), written in such a way as to make one almost feel that the old lake is there still.

Nor has Prof. Gilbert neglected those more practical matters that press themselves on officers of a Geological Survey, for he has written also on the Underground Water of the Arkansas Valley; but the lake-fever keeps with him, and has led him to take up the question of recent earth-movements in the region of the Great Lakes, on which we had from him an elaborate essay in 1898, leading to the conclusion that change is still going on, and pointing out the results that will occur if it continues.

We feel that Prof. Gilbert is an honour to the Survey of which he has long been an officer, and a worthy successor of his countrymen James Hall and J. D. Dana as our Wollaston Medallist, for his work is not only American, but appeals to the world at large.

Mr. White replied in the following words:—

Mr. President,—

It has given me great pleasure to attend this interesting meeting to-day, and to receive on behalf of my fellow-countryman,

Prof. Gilbert, the Wollaston Medal which has been awarded to him by the Council of this Society for important researches concerning the mineral structure of the earth—an honour which, as you have just pointed out, has hitherto been conferred upon two other Americans only, the late James Hall and the late J. D. Dana.

Particularly gratifying has it been to me, as I am sure it will be to all who know Prof. Gilbert, to hear, from the statement which you have just read, how highly his work is appreciated by the Geological Society of London. He deeply regrets that it should not have been possible for him, owing to engagements of a pressing nature at home, to come here to-day and to receive this Medal himself, but I shall not fail to inform him of the very kind manner in which its presentation has been made, and of the applause which has greeted each mention of his name at this meeting.

I beg to thank the Council of this Society most sincerely, on Prof. Gilbert's behalf, for the honour thus conferred upon him, an honour which he highly appreciates, as does the United States Geological Survey, of whose staff he has been a distinguished member since its foundation in 1878.

Perhaps I may be permitted, as one who has been closely connected for many years past with the diplomatic relations between the United States and Great Britain, to add that I always welcome with especial pleasure occasions of this kind, on which marks of appreciation are conferred by Scientific Societies of one country upon eminent men of the other, as they not only tend to draw more closely together the people of Great Britain and America, but they demonstrate to the rest of the world that the two nations are working together for the furtherance of science, and consequently for the advancement of civilization.

Award of the Murchison Medal.

The President then handed the Murchison Medal, awarded to Baron Adolf Erik Nordenskiöld, F.M.G.S., of Stockholm, to His Excellency Count Carl Lewenhaupt, Minister for Sweden and Norway, for transmission to the recipient, addressing him as follows :—

Your Excellency,—

Baron Nordenskiöld has given much of his time to the arduous work of Arctic exploration, having visited Spitsbergen twice, the

first time in 1858, with Torell. Again, in 1868 he organized and started another Arctic expedition, and in 1872 he discovered the great masses of native iron of Ovifak, originally described to our Society as meteorites, and also brought home a large collection of fossil plants, from which we learnt much as to the long-past climatic conditions of the Arctic regions.

In 1875 he went up the Yenisei from the Kara Sea; three years later he first doubled the northernmost point of the Old World, and reached Japan in the latter part of 1879, making what is known as the North-east Passage.

In 1883 he undertook a second voyage into the interior of Greenland, adding largely thereby to our knowledge of its glacial conditions.

Among the records of these expeditions, his book entitled 'The Voyage of the *Vega*,' which has been translated into English, and whence we derive much information as to inland ice, glaciers, and icebergs, as also his work on 'The Second Swedish Expedition to Greenland,' are notable.

We have also to thank him for giving us an English version of some of his work, chiefly in the pages of the Geological Magazine, in vol. ix of which (1872) is a set of papers on the Expedition to Greenland in 1870, while in the volume for 1875 we find the Lecture on the Former Climate of the Polar Regions, and in that for 1876 a set of papers on the Geology of part of Spitsbergen and a discourse on the distant Transport of Volcanic Dust.

Both as an observer and as an organizer of expeditions of discovery has Baron Nordenskiöld earned our gratitude, of which this Murchison Medal is a token.

His EXCELLENCY replied in the following words:—

Mr. PRESIDENT,—

On behalf of Baron Nordenskiöld, I beg to express his deep gratitude for the great distinction conferred upon him by the Council of the Geological Society. I shall not fail to transmit the Medal at once, but I may perhaps be allowed to mention that I have been asked to present the accompanying cheque as a donation from Baron Nordenskiöld to the British Antarctic Fund. It is a great pleasure for Baron Nordenskiöld to have this opportunity of proving his good wishes for the success of this expedition.

Award of the Lyell Medal.

In presenting the Lyell Medal to Mr. John Edward Marr, F.R.S., the President addressed him as follows :—

Mr. Marr,—

From 1876 onwards you have contributed fourteen papers to our Journal, most of them on the Geology of the Lake District and its borders, but two being on Welsh and two on European geology. Of these one may specially note those on the pre-Devonian Rocks of Bohemia, on the Stockdale Shales (written in co-operation with our lamented friend Nicholson), on the Shap Granite and its Associated Rocks (jointly with Mr. Harker), and on Limestone-knolls.

These papers that you have given us are enough to prove your power as an observer and a reasoner both in the field and at home; but you have also contributed much to the Geological Magazine, often in association with other workers, and I may remark that the frequent coupling of your name with other names shows how your aid is valued and how well you can work with others. Nor is this all: other journals have been enriched by your pen, and you have added the following books to the literature of Geology :—'The Classification of the Cambrian and Silurian Rocks,' 'The Principles of Stratigraphical Geology,' and 'The Scientific Study of Scenery.'

Undoubtedly your long continuous service on the Council (from 1885 to 1899) has alone hindered us from thus acknowledging the value of your work until now.

The award of the Lyell Medal may bring an additional pleasure to you in that it has been given to Nicholson, with whom you have so often worked, and to Hughes, whom you have so greatly assisted in the teaching of geology at Cambridge.

We are proud to add your name to the roll of Lyell Medallists.

Mr. Marr, in reply, said :—

Mr. President,—

In thanking the Council for the very gratifying and unexpected honour which they have conferred upon me, I feel that they must have been influenced in their choice by personal considerations, as I have been so long among them. The Founder of the Medal stated that the recipient must have 'deserved well of the science,' which in the present case could only be so in that I have tried to

do my best; I will endeavour, however, by working in the future, to 'justify the honour.'

You have mentioned, Sir, original work and teaching as qualifications. As regards original work, I have been singularly fortunate in the co-operation of the late Prof. Nicholson, and in that of Mr. Harker and Mr. Garwood. As a teacher, I am glad to see two of my old pupils receiving awards on this occasion, as it shows how happy I am in the nature of my classes. But I feel that the teacher's influence must count for something, and I know it by experience, as a pupil of the Woodwardian Professor. I am glad to take the present occasion to bear testimony to Prof. Hughes's guidance of his pupils' work—a guidance by no means exercised solely in the lecture-room.

As one who was brought up in Lyellism, and am still being brought up in it, I am unaffectedly glad that the Lyell Medal has been awarded to me. I do not use the term Lyellism in a narrow sense, as a crystallized set of tenets, which will ever retain the form in which they were left at the Founder's death. I regard it rather as possessing vitality, and as ever growing and spreading its seed, like a goodly tree.

In conclusion, while thanking you, Sir, for the kind words which you have used in presenting the Medal, I beg to call your attention to the fact that it is 25 years since you have shown me your first kindness, and that kindness has continued ever since. I am especially glad to receive the Medal from your hands.

Award of the Wollaston Donation Fund.

In presenting the Balance of the Proceeds of the Wollaston Donation Fund to Mr. George Thurland Prior, M.A., of the Natural History Museum, the President addressed him as follows:—

Mr. Prior,—

In the course of the last thirteen years you have contributed a number of papers to the Mineralogical Society, either alone or in conjunction with other observers, in which you have described minerals from various parts of the world. In the case, indeed, of one of the late numbers of the Mineralogical Magazine, there would be little left were the five papers wholly or partly written by you taken out. In three cases you have done us the service of showing that certain minerals had been christened more than once. You

have, moreover, strayed from the path of pure Mineralogy into the ways of Petrology, and have always been ready to let geologists have the advantage of that valuable help which your position in the Natural History Museum enables you to give them.

We are glad to find that our great National Museum continues to keep to the front in Mineralogy, and that we may look forward to the continuance of able observers among its officials. The Wollaston Fund is most fittingly awarded to this end.

Mr. PRIOR replied in the following words:—

Mr. PRESIDENT,—

I wish to express my heartfelt thanks to the Council for the honour which they have done me in conferring this Award. That it should be connected with the name of Wollaston is to me an additional pleasure, since my work has been mainly of a chemical and mineralogical character.

Mineralogists are perhaps rather apt to pay too little attention to the modes of occurrence and mutual associations of the minerals that they study. To try in future to make my mineralogy more geological in its character will, I feel, be the best way for me to show my high appreciation of this generous recognition from the Council, and of the kind words with which you, Sir, have accompanied it.

AWARD OF THE MURCHISON GEOLOGICAL FUND.

The PRESIDENT then handed the Balance of the Proceeds of the Murchison Geological Fund, awarded to Mr. A. VAUGHAN JENNINGS, F.L.S., to Prof. J. W. JUDD, C.B., LL.D., F.R.S., for transmission to the recipient, addressing him as follows:—

Professor JUDD,—

Mr. Vaughan Jennings has done much work in Physical Geology and in Petrology, especially in the papers which he has given us on the country around Davos in Switzerland, and he has done this despite long and severe illness. Driven abroad by that illness, he has used the opportunity thus afforded to investigate the geological structure of the district in which he has been compelled to live and to unravel the geological history of the great valley of the Engadin.

We hope that this Award may not only show him that his work, done under such disadvantage, is appreciated by us, but may also cheer him in time of trouble and encourage him to continue his labours.

Prof. JUDD, in reply, said:—

Mr. PRESIDENT,—

I wish to express my great regret that the state of Mr. Vaughan Jennings's health and the illness of a near relative prevent him from being present to receive the Award in person, and therefore beg to read the following words of acknowledgment of the honour done to him:—

'In endeavouring to express my thanks to the Council of the Geological Society for the honour which they have conferred upon me, I feel that my remarks must be of an apologetic character. Though much of my time for many years has been devoted to geological matters, my contributions to original research in that science have been far less than I wished and hoped.

'The reason—or, perhaps, I should say, the excuse—for this, lies in an unfortunate interest in the sister sciences of Zoology and Botany, and in the fact that most of my time has been devoted to teaching. While most of the Fellows of this Society doubtless recognize, in theory, the value of an equal study of the three branches of Natural History, it must be hard for many to realize the difficulty of putting the theory into practice, and the limitation which such an attempt must impose on one's efforts to do special work in any particular branch.

'The consciousness that I have been led astray into the mazes of Invertebrate Anatomy and the devious paths of Cryptogamic Botany, makes me feel still more grateful that geologists have recognized some slight value in my contributions to our knowledge of the earth.

'My first attempt in Alpine Geology is almost certainly my last; but the Council may rest assured that their kind recognition of my efforts will encourage me to work, as long as I am able, for the advancement of our science in whatever way is possible. That I have been capable of accomplishing anything in this direction is chiefly due to my studentship at the Royal College of Science, and to the kindly help of those connected with that institution.

'Perhaps I may be allowed to express also my great regret that, by accident (as I was travelling during the final revision), no

acknowledgment was made in my last paper of the kind and constant assistance vouchsafed to me by Prof. Bonney during the progress of the work.'

Award of the Lyell Geological Fund.

In handing the Balance of the Proceeds of the Lyell Geological Fund, awarded to Miss Gertrude L. Elles, of Newnham College, to Prof. T. McKenny Hughes, F.R.S., for transmission to the recipient, the President addressed him in the following words:—

Professor Hughes,—

After some stratigraphical work in the Lake District and in North Wales, done with Miss E. M. R. Wood, Miss Elles gave special attention to the Graptolites, and we have had from her a paper on the subgenera *Petalograptus* and *Cephalograptus*, adding much to our knowledge of the characters and range of those fossils, followed by the still more important paper on the Graptolite-fauna of the Skiddaw Slates, in which, after a mass of descriptive details, the phylogeny of the group is discussed at some length.

This has been followed by a paper, as yet unpublished, in which her knowledge of the Graptolites is applied to the zonal classification of the Wenlock Shales of the Welsh Borderland. We hope that this Award from the Lyell Geological Fund will show her that her work is valued and will encourage her to continue it.

Prof. Hughes replied as follows:—

Mr. President,—

I am glad to have been asked to receive the Award from the Lyell Fund for transmission to Miss Elles, who is debarred by circumstances over which she had no control from standing here to receive for herself this mark of recognition which the Council of the Society have bestowed upon her.

The research by which she has won for herself a prominent place among geologists might seem of limited scope to all but a few who know the difficulty and the importance of the group of organisms to which she has chiefly devoted her attention.

I am much pleased, therefore, to be here to-day to testify that Miss Elles, who is Assistant Demonstrator in my Department at

Cambridge, has shown herself to be a clear-sighted stratigraphist and an astute palæontologist over a much wider field than might appear, from the mention of the work for which this Award has been made, and that she is, besides, accomplished in other and altogether different branches of culture.

Miss Elles has asked me to communicate her thanks in the following terms:—

'Please convey to the Council of the Geological Society my warmest thanks for the great honour which they have so unexpectedly conferred in awarding to me the Lyell Fund for this year.

'I have been able to do so little as yet that I am bound to regard it as an incentive to future work, rather than as a reward for anything accomplished. I can only add that I will strive my very utmost to make the work which I may do in the future worthy of the confidence which such an Award seems to imply.'

Awards from the Barlow-Jameson Fund.

The President then handed to Mr. George C. Crick, A.R.S.M., of the Natural History Museum, a moiety of the Proceeds of the Barlow-Jameson Fund, addressing him as follows:—

Mr. Crick,—

In the course of the last ten years you have made yourself an authority on Fossil Cephalopoda, and have contributed several papers on various branches of this subject to the Geological Magazine and other journals, among which one may note, as of high general interest, your long and well illustrated essay on the muscular attachment of the animal to the shell, published in the Transactions of the Linnean Society in 1898: a subject which had escaped the attention of palæontologists until you drew attention to it.

Your official work at the Natural History Museum has included the making of the List of Types and Figured Specimens of Fossil Cephalopoda and the preparation of vol. iii (in conjunction with Dr. A. H. Foord) of the Catalogue of Fossil Cephalopoda in that Museum, and you have kept up the high character of that public establishment for readiness to impart information to the enquiring geologist.

Mr. CRICK replied in the following words :—

Mr. PRESIDENT,—

I beg to express my sincere thanks to the Council of the Geological Society for the great and unexpected honour that they have conferred upon me; and to you, Sir, for the kind words with which you have accompanied the Award. Considering the many privileges that pertain to my official connexion with the British Museum, the amount of work which has been done by me is comparatively so small that I regard the Award as an encouragement to continue my work, rather than as a recognition of that already accomplished.

In presenting to Prof. THEODORE THOMAS GROOM, M.A., D.Sc., the other moiety of the Proceeds of the Barlow-Jameson Fund, the PRESIDENT addressed him as follows :—

Professor GROOM,—

While at Cambridge you gave us two papers on palæontological and petrological subjects, and since then we have had from you, together with Mr. Lake, a paper on the Llandovery Rocks of Corwen, in which special reference is made to the structure of the district. Carrying out this line of research, you have contributed two elaborate papers on the Geological Structure of the Malverns, one of which is but lately published; and in these you have shown your knowledge of some of the latest methods of stratigraphical research, and your power of applying them to the elucidation of important problems in a somewhat difficult district. I trust that this Award may be an encouragement to you to continue your good work.

Prof. GROOM replied in the following words :—

Mr. PRESIDENT,—

The scientific investigator has many and varied sources of pleasure: among the greatest of these must be reckoned the sympathies of his fellow-workers, and the appreciation of his efforts by those best qualified to judge. It is, therefore, with peculiar satisfaction that I understand from your kind words, and from the honour which the Council of the Geological Society have conferred upon me, that my work has met with approval.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

William Whitaker, B.A., F.R.S.

In the past year we have lost four Foreign Members and two Foreign Correspondents. Of our Fellows we have lost three who may be described as geologists or palæontologists of world-wide fame, and several others well known in our own country or more widely known for other than geological attainments.

Prof. Robert Wilhelm Bunsen was elected a Foreign Member in 1856, and died on August 16th, 1899.

He was born on March 13th, 1811, and was our senior Foreign Member. Though he achieved his great reputation as a chemist, and held the Chair of Chemistry in the University of Heidelberg for many years, he wrote (especially in his earlier years) several papers on minerals and on mineral waters, as well as on various geological subjects, notably on the chemical geology of Iceland.

To the scientific world he is largely known for his work on spectrum-analysis, resulting in the discovery of the elements cæsium and rubidium; while to the world at large he is known by the invaluable gas-burner that bears his name and the principle of which he discovered.[1]

Prof. Hanns Bruno Geinitz was elected a Foreign Member in 1857, and died on January 28th, 1900. He was Murchison Medallist in 1878.

After the death of Prof. Bunsen, Geinitz became the oldest of our Foreign Members, and in him we lose the last who has not passed through the ranks of the Foreign Correspondents.

He was born at Altenburg in October 1814, and studied at the Universities of Berlin and Jena, taking the degree of Ph.D. in 1837 with a thesis on the Muschelkalk of Thuringia. He went to Dresden in 1838 to take part in the work of the Royal Technical High School, in which he became Professor of Mineralogy and Geognosy in 1850, maintaining his connexion with that establishment until 1894. In 1857 he was made Director of the Royal Mineralogical and Geological Museum, which post he also held until 1894.

His work related chiefly to Saxony, and to it we are specially

[1] For a fuller notice of his life and work, see the Year-book of the Royal Society for 1900, pp. 198–202.

indebted in regard to the palæontological relations of that kingdom, but it also dealt with other parts of Europe. Among his more notable works are those on the Fossils of the Coal Measures of Saxony, on the Cretaceous Formations of Saxony, comparing them with those of England, on the Animal Remains of the Permian, and on the Elbthalgebirge of Saxony, and these are the more valuable from being well illustrated.

He received many orders and honours, held various offices, and was highly revered as a teacher and leader.[1]

Franz Ritter von Hauer was elected a Foreign Correspondent in 1863, and Foreign Member in 1871. He was Wollaston Medallist in 1882, and died on March 20th, 1899.

He has been called the Nestor of Austrian geologists, having been for many years Director of the Geological Survey and Chief Curator of the Imperial Natural History Museum.

He was born in Vienna in 1822, and educated there until he went to the Mining Academy at Schemnitz, where he remained from 1839 to 1843. He afterwards became a mining official in Styria, and in 1846 was made Assistant to Haidinger at the Imperial Mineralogical Museum in his native city, when he began original palæontological work. He succeeded Haidinger as chief of the Museum, and held that post from 1867 to 1885.

On the death of F. von Hochstetter he was made Chief Curator of the Imperial Natural History Museum, in which post he did important work, retiring at last on account of old age and ill health.

He was the first to classify the Alpine sedimentary rocks on a strictly stratigraphical basis, and published a work on the Cephalopoda of the Trias and Jura of the eastern Alpine regions. His general map of the Austrian Empire (in 12 sheets, published 1867–71, reaching a fourth and extended edition in 1884), and his account of the geology of that empire, published in 1875, fittingly crown his works.[2]

Prof. Othniel Charles Marsh was elected a Fellow in 1863, and was transferred to the list of Foreign Members in 1898. He was the first Bigsby Medallist (1877), and died on March 18th, 1899.

[1] See also the obituary notice in Geol. Mag. 1900, pp. 143–144.

[2] From a notice by Vaček in Verh. k.-k. geol. Reichsanst. 1899, no. 4, pp. 119–126.

Born at Lockport (New York) on October 29th, 1831, he was educated at Yale College and at the Universities of Berlin, Breslau, and Heidelberg. Becoming Professor of Palæontology at Yale in 1866, he held the chair until his death, and he was Palæontologist to the United States Geological Survey for many years.

He organized various expeditions into the Rocky Mountains, leading to the discovery of huge reptiles, toothed birds, and mammals in the Eocene, Cretaceous, and Jurassic of the Western States. These discoveries were described in various papers, chiefly in the American Journal of Science (of which he was an Associate Editor); but the most important records of his work are the two large monographs on Odontornithes, published in 1880, and on Dinocerata, published in 1884; a third on Saüropoda was just completed when the hand of Death lay upon him.

He was President of the American Association for the Advancement of Science in 1878, and also of the National Academy of Science for several years.

Marsh was personally familiar to many of us, as he often visited England, and attended various meetings of the British Association. In one case he wrote on English geology, advocating the classification of our Wealden as of Upper Jurassic age, rather than as Lower Cretaceous.

Charles Jules Edme Brongniart, Docteur-ès-Sciences, was elected a Foreign Correspondent in 1888, and died on April 18th, 1899, at the comparatively early age of 40.

He was Assistant at the Museum of Natural History, Paris, and one of the chief European authorities on fossil insects, on which he wrote a number of papers from 1876 onward. His principal work was published in 1893, when he issued two large and important volumes, both with atlases of plates. One of these is the 3rd vol. of Studies on the Coal Measures of Commentry, devoted to the Entomological Fauna. The other deals with the Fossil Insects of Primary Times. It is sad that so distinguished a career should have been thus cut short in full activity.

Prof. Louis Lartet was elected a Foreign Correspondent in 1882, and died in 1899.

He was the son of our former distinguished Foreign Member, Edmond Lartet. In 1863 he assisted De Verneuil in two papers, and from 1864 to 1868 he published several memoirs of his own, chiefly on the Holy Land, leading up to his lengthy essay on the

Geology of Palestine and of the neighbouring countries (1869), followed, three years later, by a shorter paper on the Palæontology of the same region.

His work was presented in a more elaborate form in 1877 in the large quarto volume entitled 'Geological Exploration of the Dead Sea, Palestine, and Idumæa,' with two geological maps, three plates of sections, and eight of fossils and stone-implements. By these works he is chiefly known.

Walter Joseph Baker, who was elected a Fellow of this Society in 1886 and died on July 29th, 1899, was a prominent member of the well-known firm of Baker & Sons, well-sinkers of long standing. He took considerable interest in geological matters, and was always ready to contribute to our knowledge from the stores of information acquired by his firm. I have had to thank him often for valuable records, and in him I lose a friend.

William Young Campbell was elected a Fellow in 1890, and died on April 21st, 1899. He was well known among Anglo-Africans, in connexion with gold-mining, and as head of the South African Trust & Finance Company.

Prof. Samuel Cooke, M.A., Assoc. Mem. Inst. C.E., was elected a Fellow in 1877, and died on February 26th, 1899.

He was appointed Professor of Chemistry and Geology in the Poona Engineering College (India) in 1868, becoming Principal of the College of Science in the same city in 1893, having acted in that capacity on several previous occasions. In 1897 he published a work entitled 'The Foundations of Scientific Agriculture,' in which his geological knowledge was deftly applied.

Sir J. William Dawson, C.M.G., F.R.S., was elected a Fellow in 1854, and died on November 19th, 1899. He was Lyell Medallist in 1881.

Born in 1820, at Pictou (Nova Scotia), he was educated there and at the University of Edinburgh, where he took the degree of Master of Arts in 1842. He then accompanied Sir Charles Lyell in the latter's journey through Nova Scotia, on the geology of which he worked persistently, collecting his results in the work on 'Acadian Geology,' which has passed into a third edition.

He contributed to our Society a long series of papers on the geology and palæontology of Nova Scotia, Canada, etc., which are

published in the volumes of our Journal from the first to the fiftieth, and also gave another great series to Canadian and other Societies for a period of more than forty years up to 1898. Many other publications were indebted to him, and he wrote two volumes on the Devonian and Carboniferous Flora for the Geological Survey of Canada, besides works of a more general character. He will always be known in connexion with *Eozoon canadense*, the organic origin of which he steadily upheld.

In public life he occupied a conspicuous position, having been appointed Superintendent of Education for Nova Scotia in 1850, and Principal of McGill University, Montreal, five years later. In his 38 years' tenure of this latter post he exercised a powerful influence in the promotion of University education throughout the great Dominion, besides doing much other educational work.

He was successively President of the Royal Society of Canada, of the American Association for the Advancement of Science, of the British Association, and of the American Geological Society. He was elected a Fellow of the Royal Society in 1862 and knighted in 1884. His high personal character and his fine presence helped to make him one of the most prominent men in Canada.[1]

George Dowker, elected a Fellow of this Society in 1864, died on September 22nd, 1899.

It is again my lot to record the death of a very old friend, to whom I have been indebted for much kindness.

George Dowker was born at Stourmouth in 1828, and educated first at Sandwich Grammar School and then at an agricultural college. He lived for the greater part of his life at Stourmouth, farming his own estate, devoting much attention to various branches of natural history (including geology) and to the study of local antiquities. He wrote several papers on East Kentish geology, and in later life, after giving up his farms and settling at Ramsgate, he specially interested himself in the subject of later changes of land, coast-erosion, etc., as to which he became an acknowledged authority. His knowledge of botany helped to place him at the head of local observers in East Kent, and his skill with the pencil aided him in this as well as in his geological work. He was also an early user of the camera for geological purposes.

He was one of the earliest Members of the Geologists' Association,

[1] Some further particulars are given in Geol. Mag. 1899, pp. 575–76.

having joined it at its beginning in 1858, and he helped it often, both as a reader of papers and as a leader of excursions.

A good observer, an enthusiastic worker, unselfish and kind-hearted, his end was probably as he would have wished, and we may say a happy one, for he died in harness. He took a large share in the work of the British Association at Dover, helping in the local arrangements. He attended the meeting, read a paper (since privately printed) on Coast-erosion, illustrated by his own lantern-slides, and at the end of the meeting conducted the excursion to Richborough on the Thursday (September 21st), being in good spirits and apparently in good health. But he returned home the next day only to die, from failure of the heart's action.

R. A. Eskrigge, J.P., was elected a Fellow in 1866, and died on November 11th, 1898.

By some oversight the death of this gentleman was not reported until some time after the last annual meeting. Many years ago he did some useful geological work in Lancashire and Cheshire.

Sir William Henry Flower, K.C.B., F.R.S., Pres. Z.S., elected a Fellow of this Society in 1866, died on July 1st, 1899.

He was born in 1831 at Stratford-on-Avon, and received his medical education at University College, London, where he had a distinguished career.

He served as an Assistant Surgeon in the Army during the Crimean War, and then became Assistant Surgeon in the Middlesex Hospital; but in 1861 he gave up practice on becoming Curator of the Hunterian Museum, succeeding to the Hunterian Professorship in 1869, and holding the two posts until 1884, when he became Director of the Natural History Museum, which post he held for 14 years. He gave us papers on the Affinities of *Thylacoleo* and on two Red Crag mammals, *Halitherium* and *Hyænarctos*.

Flower received many honours in recognition of his zoological as well as of his public work; but his greatest distinction is that he became our chief authority on natural history museums, the organization and educational development of which formed the great work of his well-spent life.

His kindness and courtesy made him popular among his fellows, and the beautiful memorial service held at St. Luke's Church, Chelsea, was fully attended, our own Society being strongly represented.[1]

[1] See also a long notice by Dr. H. Woodward in Geol. Mag. 1899, pp. 381–84.

Sir Douglas Strutt Galton, K.C.B., F.R.S., was elected a Fellow in 1848 and died on March 10th, 1899. He was among our oldest Fellows, and served on the Council from 1870 to 1874.

Born in 1823 at Hadzor House (Worcestershire), at the age of 15 he entered the Royal Military Academy, and in 1840 obtained a commission in the Royal Engineers, greatly distinguishing himself and gaining the first prize in every subject of examination.

He was engaged in the attempt to raise the *Royal George*. Subsequently he served on the Ordnance Survey, and did much work in connexion with railway-engineering, metropolitan drainage, submarine cables, and the sanitary condition of the Army, besides sitting on various Royal Commissions, etc. In 1860 he was made Assistant Inspector-General of Fortifications, and in 1862 Assistant Under-Secretary of State for War, a post which he held for eight years, when he became Director of Public Works and Buildings (under the Board of Works), in which capacity he served until 1875.

He was General Secretary of the British Association from 1871 to 1895, in which latter year he became President. In 1894 he was made an Honorary Member of the Institution of Civil Engineers, and many other honours were bestowed upon him, including various foreign orders of knighthood.

The later years of his life were specially devoted to sanitary science, in the development of which he greatly assisted, and his last official appearance in public was as president of a meeting of the Sanitary Institute, for the reading of a paper on the water-supply of London. He was then rather indisposed, though no serious malady was suspected; but he gradually became weaker, and blood-poisoning set in, with fatal results.

He was buried at Hadzor, and two days later a memorial service was held at St. Peter's, Eaton Square, when the whole of that large church was filled, for Douglas Galton had very many friends. I regret that, owing to a mistake, I was not present, although our Society was represented, for I always held him in high regard.[1]

Townshend Monckton Hall was elected a Fellow of this Society in 1865, and died on July 1st, 1899.

Born at Torquay on March 22nd, 1845, he studied for a short time at Wadham College, Oxford. On leaving there he devoted

[1] The above account is chiefly compiled from notices in Journ. San. Inst. vol. xx, pp. 184–90, and in Proc. Inst. Civ. Eng. vol. cxxxvii, pp. 413–17.

himself to science, and especially to geology. A paper by him on the distribution of fossils in the North Devon Series was printed in our Journal; but his chief contributions to the geology and mineralogy of his native county are to be found in the Transactions of the Devonshire Association (of which he was a member from the first), and include papers on mineral localities, raised beaches, submerged forests, concentric lamination, mineral oil, the classification of North Devon rocks, and various matters of local geology. He also contributed to the Geological and Mineralogical Magazines, and wrote several sketches of the Geology of Devon or part thereof as well as the 'Mineralogists' Directory.' He became, indeed, our chief local authority on North Devon.

Dr. Henry Hicks, F.R.S., was elected a Fellow of this Society in 1871, and died on November 18th, 1899. He served on the Council from 1875 to 1880, 1884 to 1888, 1890 to 1893, and from 1896 onward. From 1890 to 1892 he was Secretary, and President from 1896 to 1898. He received the Bigsby Medal in 1883.

Henry Hicks was born at St. David's in 1837, and educated first at the Cathedral School there and afterwards at Guy's Hospital. He entered upon medical practice at his native place in 1862, and soon began geological work there, being greatly stimulated by that able palæontologist, Salter. The fruits were a great number of papers on the geology and fossils of the district, read to this Society and published in its Journal from vol. xxi onward, besides many in other publications. One notable piece of work was the discovery of fossils in the Lower Cambrian rocks and the subdivision of those rocks.

Nor was this Welsh work confined to the period when he lived at St. David's, being continued after he settled near London in 1871, after which time his field of observation naturally became extended. He carried his researches into the pre-Cambrian rocks, not only in his old district but also in other parts of Wales and in Scotland; he made researches in Bone-caves and carefully recorded sections in the Glacial Drift round his home at Hendon, as well as sections in our London gravel and loam. Moreover he took up Devonian geology, contributing many papers on these and allied subjects to our Journal, to the Geological Magazine, and to the Proceedings of the Geologists' Association. To that Association he gave much help in excursions, and was President thereof from 1883 to 1885.

In such questions as the pre-Cambrian rocks, the geology of the Scottish Highlands, the classification of the older beds of Devon,

etc., the age of Bone-caves, and other matters connected with Drift geology he became often involved in controversy; but in this he was as ready to receive as to give, and, despite his impulsive nature, did not allow scientific differences to degenerate into personal antagonism, a feeling for which he was too kind-hearted.

Dr. Hicks took part in various matters of a more or less public character, and, after giving up general practice, became the head of a large private asylum; so that the pursuit of geology was his recreation.

His death came as a sad surprise, none of us being prepared for it. An attack of rheumatic gout last autumn affected his heart, and proved fatal. Not only is the loss of him felt as the greatest among our home-geologists in the past year, but also because we miss the genial, kindly, active presence of my immediate predecessor in this chair.[1]

Lord Hylton (H. H. Jolliffe) was elected a Fellow in 1865, and died on October 30th, 1899.

Born at Merstham on June 23rd, 1829, he was educated at Eton and Oxford, then entered the Army and served in the Crimean War, taking part in the Charge of the Light Brigade. He was Member of Parliament for Wells from 1855 to 1868, and succeeded to the peerage in 1876. I believe that he was the first to draw the attention of geologists to the fine new railway-cutting at Merstham.

Sir Frederick McCoy, K.C.M.G., F.R.S., was elected a Fellow of this Society in 1852, and died on May 16th, 1899. He was Murchison Medallist in 1879.

McCoy was born in Dublin in 1823 and educated at the Universities of that city and of Cambridge for the medical profession, which, however, he afterwards gave up for natural science. He was Sedgwick's assistant at Cambridge, helped Sir Richard Griffith by palæontological work for his geological map of Ireland, afterwards joined the Geological Survey of Ireland, and was made Professor of Geology in the Queen's University, Belfast, in 1850. Four years later he became the first Professor of Natural Science in Melbourne University, a post which he held for the rest of his life.

His palæontological labours were extensive, and among them are conspicuous the great work (written in conjunction with Sedgwick)

[1] An appreciative notice of Hicks and of his work has been written for the Royal Society, for a proof of which I have to thank its author, Prof. Bonney.

in which the British Palæozoic Fossils in the Woodwardian Museum are described, and the Palæontology of Victoria. He was the founder of the National Museum at Melbourne, of which he held the Directorship until his death, and was also Palæontologist to the Geological Survey of Victoria.

The only paper that we had from him is a short criticism on some supposed fish-remains, published in 1853; but he contributed many to the 'Annals & Magazine of Natural History' and to the Royal Society of Victoria.

Many honours were conferred on him, and he was recognized as the leading scientific man in Australia.[1]

John Baldry Redman was elected a Fellow in 1882, and died on December 21st, 1899, at the age of 83. He was elected an Associate of the Institution of Civil Engineers in February 1839, and a Member in March 1846, his name being the oldest on the roll of over 6300 Members and Associates at the time of his death.

He did much service to geology by his important papers, read to the above-named Institution, 'On the Alluvial Formations & the Local Changes of the South Coast of England,' and 'The East Coast between the Thames & the Wash Estuaries,' published in 1854 and 1865, which gave the first systematic account of the changes along a great length of our coast, in this case from Norfolk southward to Dorset. Much other work of the kind was also done by him, for instance in the Reports of the British Association Committee on Coast-erosion, and his knowledge was always freely placed at the disposal of those interested in the subject.

John Ruskin, who was elected a Fellow of this Society in 1840, and died on January 20th, 1900, was one of our oldest Fellows, there remaining, indeed, but two senior to him. His career and his great services to art and to literature have been recorded in many publications; but we must not forget his services to our science, in directing the attention of artists and others to the effect of geological structure and of the characters of rocks on scenery. This is especially exemplified in what is, perhaps, his greatest work, 'Modern Painters,' and I would refer to four chapters of vol. i, entitled 'Truth of Earth' (pp. 265–319), and to the magnificent fourth volume, devoted to 'Mountain Beauty,' eleven chapters of which

[1] See also Geol. Mag. 1899, pp. 283–87, with a list of his papers, and the Year-book of the Royal Society for 1900, pp. 196–98.

on the 'Materials of Mountains,' 'Sculpture of Mountains,' and 'Resulting Forms' (pp. 107–324) might be read with advantage by many geologists.

Although he contributed no paper to this Society, he referred to the structure of the Alps in the second volume of the Geological Magazine (1865), and in vols. iv to vii (1867–70) contributed a set of papers on banded and brecciated structures, enriched with seven beautiful plates.

Major-General Alexander de Courcy Scott, R.E., Assoc. Mem. Inst. C.E., was elected a Fellow of this Society in 1890, and died on October 16th, 1899.

He served at the siege of Sebastopol, and retired from the Army in 1882. He was appointed Water Examiner for the Metropolis in 1871.

Major R. T. W. Lambart Brickenden, who was a Fellow of this Society from 1848 to 1896, contributed several papers on Scottish geology to our Quarterly Journal.[1] He resigned in the last-mentioned year, and died an octogenarian in 1899.

I may fairly conclude these obituary notices with a reference to a person never enrolled among our Fellows, prevented from being so, indeed, by sex alone. The niece of Falconer, the wife of Prestwich, lived little more than long enough to see the production of the labour of her latest years, the Life of her husband.[2] This work of love is one of the most notable of the geological books of last year, and it gives an account of the life and labours of one of our greatest geologists, illustrating the way in which he was led to take up those various lines of research wherein he so highly distinguished himself.

Grace Anne, Lady Prestwich, died on August 31st, 1899, at the age of 66, to the sorrow of all who knew her.

[1] See General Index to the first Fifty Volumes of the Quarterly Journal, 1897, p. 59.

[2] 'Life & Letters of Sir Joseph Prestwich,' by His Wife; pp. xvi & 444, 8vo. London, 1899.

It is sometimes well for us to look back and to notice the progress that has been made in our science of late years. In adopting this course it has occurred to me to take the somewhat indefinite term of my own geological life, whether from the time when I first studied geology under Prof. Morris; or when I began to devote myself especially to the science, as an officer of the Geological Survey, in 1857; or when I had the honour of becoming a Fellow of this Society some two years later.

At the time when I was a student at University College, London, laboratory training for the embryo geologist was not to be had: the only available practical work was in excursions, to see rocks in the field; and in this matter Morris was a master, as all who knew him will bear witness. Indeed we may say that he was the first, or among the first, of that now large band of able guides who can explain the geological structure of their districts in the field in such a manner as to make it clear to anyone possessed of ordinary intelligence, though perhaps not of any great amount of geological knowledge.

In one respect only could the students of those times claim a fairly equal advantage with those of to-day, that is, in having able and zealous men to teach them, and of these Morris was a notable example; but now the number is far greater than then. My old teacher, indeed, imbued his pupils with a strong liking for geological work and led them to take it up, though it was of no direct use to them in their academic career: indirectly, of course, the teaching of such a man was of inestimable service. Nowadays geology has taken its place among the studies for University degrees.

Geology was the last subject to which my student-mind was given, and I can hardly tell by what happy accident I was led to join Morris's class. It is only rendering due justice to his memory to say that the honourable position which you have allowed me to hold for the past two years could never have been mine, but for the influence which John Morris exercised on my early life.

Afterwards I had another and more multiple teacher, in the shape of the Geological Survey. Of course, as is the way with raw students, I had a pretty good opinion of my knowledge of geology when I joined that establishment, a mistaken notion speedily got rid of with the help of my genial comrades. Looking back to earlier years of my Survey life, when help and advice were most wanted, I feel bound to note the advantage of having such a chief as Ramsay, whose then unrivalled knowledge of field-geology was freely accessible

to all who served under him, whose kindliness and encouragement to the young surveyor were so marked that his visits of inspection were looked forward to not as a mere matter of business, but as an intellectual treat and as a personal pleasure.

The work of the Geological Survey is such that to a great extent its officers must perforce become their own teachers: they have to find out much for themselves, as in other pursuits of active life, and this, along with a somewhat solitary existence, sometimes entails a certain amount of despondence. Though not much given that way myself, yet I began at one time to feel it beyond my power to make out the work entrusted to me. This occurred on my first acquaintance with that peculiar deposit the Clay-with-flints, which would not fit in with what I had been taught was right and proper, but led me to differ from my friends, a discussion with whom, however, soon lifted me out of the slough of despond and led to a harmonious result. The world has progressed since then. No geologist is now troubled about that or any other like deposit, but can readily explain their peculiarities.

So much for personal matters, for alluding to which please forgive me. When I come to look at the great subjects in which notable advance has been made within my time, I find it is less a case of advance than of absolute creation, a case of the birth and growth of new ideas rather than of the improvement of old ones.

Let us look first to Petrology. Really that branch of science did not exist at the time when I was a young student. The classic paper of Sorby, by a long way our oldest living Wollaston Medallist, whom we rejoice to have still among us and still an energetic worker in the field of science, was not read to the Society until some months after I had joined the Geological Survey and not published until the following year. In this, as in other cases, new ideas need time to fructify, and the bearing of this work on the study of rocks had to be thought out. British Petrology is a product of the latter part of this century.

Before the time heralded by Sorby the microscope had been applied to geological purposes only in a very partial manner. One may say, indeed, that the variety of our species *Homo petrologicus* had not arisen; now it is well established, numerous, and fertile.

Turning to Palæontology, a different picture meets our view. In my early days palæontologists were plentiful and were doing good work, but that work differed somewhat from much that is done now, for the world had not then before it the grand results of the long labours of Darwin, whose name stands out above all others in this nineteenth century, so far as natural science is concerned. The great theory of Evolution itself had not been evolved, and it was not for many years that its immense influence on biological science was fully felt.

I well remember the publication of 'The Origin of Species,' and how Ramsay was carried away by the force and brilliance of the work: no need, perhaps, to say that I followed his lead, as we naturally had a habit of doing on the Geological Survey, and that I have always been a humble believer in Evolution, as well as in progress generally.

Nowadays we concern ourselves less than formerly was the case with mere descriptive matters, and more with the grouping and relationships of species, with the history and development of past forms of life. The palæontology of the present may be said to be more philosophic than that of the past, being concerned rather with the filling of gaps in the life-history of the world than with the recording of specific distinctions. The reign of the mere species-maker is almost at an end.

Besides a vast addition to our knowledge in all branches of palæontology, an outline of which would in itself form a long address, there has been also a great advance in the application of palæontology to stratigraphy, in the matter of that zonal classification of which we hear so much and which in some cases seems to be the chief guide in unravelling the structure of a district. It is really the application of palæontology which allies that branch of science to geology, rather than to biology. The coining of species, on the other hand, is a biological rather than a geological crime.

There is one matter in which the ways of the palæontologist are apt to be a little troublesome to the geologist, that is in the frequent changes of name. One sometimes feels, and not in this matter alone, that perfect rectitude is hardly worth the efforts that have to be made to attain it.

With regard to the physical side of our science, important advances have been recorded, notably in the domain of metamorphism, following on the rise of Petrology. In my student-days

metamorphic rocks were thought to form a sort of passage between igneous and aqueous rocks, to be neither fish, flesh, nor fowl, neither one thing nor the other: it was hardly realized that both igneous and aqueous rocks alike had been influenced by mighty changes brought about by heat, by pressure, and by movement; regional and dynamic metamorphism were terms unknown. Nor were those slow but constant actions that go on nearly everywhere, from the surface downward, at all appreciated; even yet, perhaps, we have much to learn about them.

Another marked advance is in our knowledge of great earth-movements and of mountain-structure, whether of existing ranges or of those now more or less destroyed. Overthrust-faults, crush-conglomerates, and various other phenomena now accepted as fundamental articles of faith, were not known in my early days, and had views such as those to which we are in the habit of calmly listening been brought forward then their authors would have been deemed arch-heretics or madmen.

The study of those surface-actions by which the features of our earth have been carved out has greatly progressed: indeed this subject was little considered forty years ago, while now the various methods of erosion and their resultant forms are well understood and repeatedly described.

As an illustration of our advance in some of these matters I would point to two Geological Survey Memoirs of recent date. In the earlier of these[1] the geological structure of part of Argyllshire and the metamorphism and deformation of the rocks are dealt with in great detail, part of the memoir being almost a text-book on schistose rocks. The other is the fine Memoir 'On the Silurian Rocks of Britain,'[2] the most important publication of the past year on our home-geology, dealing with petrological, palæontological, physical, and stratigraphical problems. This work is of much more than local interest, and if any further justification for the joint award of a Murchison Medal to each of its chief authors last year had been needed, this memoir would have fully supplied it.

Turning, finally, to the stratigraphical branch of our highly divisible science, on which branch alone am I qualified to speak at length, one most notable advance has been in the more detailed character

[1] 'The Geology of Cowal,' pp. viii & 333, with 10 plates, 1897.

[2] Vol. i: Scotland, pp. xviii & 749, with 28 plates & map, 1899.

of our knowledge, accompanied of course by greater precision in the recording of facts.

In this matter, perhaps, I shall not be accused of over-partiality in saying that it is largely due to the extension of Geological Surveys. There were but few when I joined our own; now there are many. One result of the continuous, more or less detailed, mapping done by Government Surveys has been to make the value of such work more widely known, and also to lead geologists, other than those employed in the work, to take it up for their own local or special purposes. It is more common now than it was in my early days to find a geologist engaged in putting his work on a map, and I hail this change with great satisfaction. The more numerous are the geologists who themselves make maps, the more will geological maps be appreciated, and the more will an official Survey be expected to produce maps giving a great amount of precise and detailed information, such as a Survey alone can do over large tracts.

The advance in the mapping-work of the Geological Survey may be noticed here, an advance depending largely on the publication of newer, better, and more detailed maps by the Ordnance Survey.

In my early days Drew started the divisions of the Hastings Beds in the Wealden area, in Kent, Surrey, and Sussex, as well as those of the Lower Greensand around its border. I wonder what we should think if our maps showed us those two formations in the lump in that large district, although we sometimes dispute as to the correlation of their divisions in various districts.

Now, in the new work, the Chalk also is separated into three, or sometimes four divisions; but this work, alas! has not yet reached Kent and Surrey. In like manner more detailed work has been done in the Tertiary beds of Hampshire and Dorset, in the Jurassic of the latter county, in the New Red and Devonian of Devon and Cornwall, in the Carboniferous and Old Red Sandstone of South Wales, and in various formations in the Midlands.

But perhaps the greatest, as certainly it is the most widespread of all improvements, is the gradual evolution of Drift-mapping. This mapping started in a generalized way, with an apparently contemptuous reference to a more or less troublesome and objectionable mass of Drift, in the lump; but the importance of these surface-deposits has become more clearly seen, so that now they are mapped according to their various lithological characters. In a few cases, perhaps, divisions, according to presumed age or origin, may be somewhat in excess; but in this the Survey maps certainly lag

behind the ingenuity of the many workers on the Drift, some of whom seem to believe in the infinite divisibility thereof.

While on this subject, I would pay a tribute of respect to a pioneer in Drift-mapping, the late S. V. Wood, Jun., whose maps, with their continuation, by his pupil Mr. Harmer, are now in the Society's possession, through the kindness of the latter.

The publication of geological maps on the large scale of 6 inches to the mile was undreamt of when I joined the Survey; but it was not very long before some of the northern coalfields were partly illustrated on that scale. Let us hope that some modern process may soon be adopted for cheaply issuing like maps for other tracts. The work being now done on the large scale, it seems a pity that it should all be practically locked up in MS. copies.

The first Memoir illustrating a sheet of the Map was published in the very year that I joined the Survey. Now there are 87 of these Memoirs illustrating sheets of the English Map, 9 for Scotland, and 118 for Ireland. In this the 'distressful country' is well ahead, every sheet being accompanied by its Memoir.

A few of the English Memoirs are really full-sized volumes, and others nearly so. Besides these, other Memoirs, with various objects and of various sizes, have appeared; and lately it has been the custom to give a pretty full account of the year's work in the 'Summary of Progress,' instead of the meagre statistics of earlier 'Annual Reports.'

I see therefore every reason to anticipate a long career of increased usefulness for that Survey to which I had the honour to belong for $39\frac{1}{2}$ years, and my association with which was so advantageous to myself, though I joined it on so ominous a day as the first of April.

Besides the great increase in detailed work on our various stratified formations, we must also remember the great extension downward in age-classification. It is not so many years ago that we knew of nothing older than Cambrian; now we know of large masses of pre-Cambrian rocks, which have a literature almost appalling in its extent, combined with a nomenclature of a somewhat confusing kind. Of this literature there is not any sign of great decrease in output, and probably very much work remains to be done on these old rocks.

The mention of this subject recalls the grievous loss which the Society has lately suffered in the death of our friend, Dr. Hicks, who was so zealous an investigator of the earlier rocks.

At the other end of the geological scale the advance of knowledge has also been very marked, as before mentioned, when noticing the Drift-work of the Geological Survey. Especially, however, has this been the case in regard to a subject perhaps of more general interest than any of those great questions to which I have already alluded or others to which I am about to refer; and naturally so, as it has a much more apparent connexion with ourselves. I mean the Antiquity of Man.

It was not until 1859 that the first of the great papers on this subject by Prestwich and by Evans were read, and these were not published in full until 1860 and 1861. Then first did we realize that it was distinctly proved that implements made by man occurred, associated with the remains of extinct mammals, in beds of undisturbed gravel and loam belonging to a late Drift age, both in France and in England. Other papers by each of the above-named authors soon followed, and the question was prominently brought before the public in 1863 by Lyell's 'Antiquity of Man,' of which three editions appeared in that year. The lately published 'Life of Prestwich' contains much interesting correspondence on the subject.

Much and sharp discussion arose, as is right; but what geologist now feels any doubt on this subject? Many, on the other hand, would feel no surprise at the age of our species being pushed somewhat further back in the world's unwritten history: indeed several zealous workers are trying so to push it.

Of course the area over which discovery has been made has been greatly extended, and a voluminous literature has arisen, a most able summary of which, so far as these islands are concerned, has been given in the great work of our Foreign Secretary.[1] Probably it is the high interest felt in this matter that has intensified the attention bestowed on the Drift.

As the discovery of stone-implements in the Drift has served to link our science with anthropology and with the study of prehistoric antiquities, so has geology been brought into contact with geography by the great amount of work that has been done on the existing features of the earth and their origin. This work includes those speculations, in which our American brethren are pre-eminent, as to former topographical features and their gradual change into those of to-day, another example of evolution.

[1] Sir John Evans, 'The Ancient Stone Implements ...... of Great Britain' (1872) & 2nd ed. (1897).

This leads me to notice the great advance of geological work in the Western Continent, especially among our colleagues in the United States. Formerly there was no Geological Society in that great domain, nor any Journal specially devoted to Geology. Now there are two of each of these. Formerly, too, only a few States had a Geological Survey, now the majority have come to appreciate the advantage of such an institution. Moreover, the central Government has carried out a series of surveys, for more or less special purposes or for particular regions, the results of which have been given to the world in bulky volumes, some with illustrative atlases. These surveys have culminated in the great national work now presided over by one of our Bigsby Medallists, C. D. Walcott, the Bulletins, Reports, Monographs, and other publications of which form of themselves a goodly geological library, well printed and splendidly illustrated, containing many memoirs that are of far more than local interest.

We are, indeed, almost overwhelmed by the flood of geological literature poured in upon us from various public sources in the United States, the liberality and generosity of whose government departments contrast strongly with the extreme economy, to use no harsher term, of our own Government. It seems unfair that the work of the zealous officers of our Geological Survey should suffer, first, from the rather parsimonious way in which it has usually been printed, and, secondly, from the fairly successful endeavour to keep it from being too widely circulated, or even known. Perhaps some distant successor in this chair may be able to chronicle a great advance in this matter in the United Kingdom. The Silurian Memoir to which I have already referred certainly shows a great improvement in printing.

There is, too, another and still more important matter upon which we may congratulate the United States: that is, on the men whom they have turned out, on the increase in their supply of able geologists. To one of the ablest exponents of American geology the Council of this Society have just given the highest award which it is in their power to bestow, the Wollaston Medal.

Underground Geology generally.

From the foregoing slight sketch it is clear that in order to deal with the advance in the leading subjects of geological knowledge during even the term of my own geological life several Addresses would be needed, and that these ought to be given by several individuals, experts respectively in the various matters to which I have

drawn attention. I soon saw that such a task was too great, and that it would be better for me to content myself with little more than passing allusions, devoting more detailed attention to a stratigraphical subject of which our knowledge has greatly increased within my time. In a small part of this advance I have been privileged to have a share, through the nature of the work that I have had to do.

That subject is the underground course of various formations, as proved by shafts and borings sunk through overlying beds. On two occasions already I have attempted to summarize our knowledge in this line, but only for special districts,[1] and it may be of some interest to take a more general view and in a somewhat different way.

Many years ago our knowledge of what was to be found deep underground was almost limited to mining districts, whether metalliferous or coal-bearing, and even in such cases the recording of details was too often neglected, the value of such details not being at that time understood. The great advantage of possessing careful records of the beds passed through in shafts or borings has now been recognized for some time, especially in such cases as trials for proving the underground extension of Coal Measures beneath not only Permian and Triassic rocks, but also beneath still higher formations, as, for instance, in part of the Bristol Coalfield.

In this work it is important to record details of the rocks above the Coal Measures, so as to have some grounds for estimating the thickness of those rocks in neighbouring localities. Thus the widening of the areas over which coal may be worked leads to further knowledge of overlying formations. Moreover, we also gain information as to the range of the various seams of coal and of the changes which those seams undergo, and are enabled to correlate sections at some distance.

The Vertical Sections and various Memoirs of the Geological Survey supply much information of this sort; but the greatest collection of such details is the fine set of six volumes published by the North of England Institute of Mining and Mechanical Engineers, embodying an account of over 2350 sections.[2]

I do not, however, mean to pursue the subject of the search for

[1] 'Underground in Suffolk & its Borders,' Rep. Brit. Assoc. 1895 (Ipswich), pp. 666–675; and 'The Deep-seated Geology of the Rochester District,' Trans. S.E. Union Sci. Soc. 1899, pp. 1–11.

[2] 'An Account of the Strata of Northumberland & Durham as proved by Borings & Sinkings,' 1878–1897.

coal, in itself almost too wide for a single Address; but to draw your attention to another source of information of a more widespread kind. The parts where coal can be worked are naturally limited, though often extensive; but the need for water is universal, and over a great extent of country water has to be got, partly or wholly, from underground sources by means of wells and borings. These, with trial-borings made for various purposes, are mostly the sole available evidence of the underground extension of various formations.

Even in this subject it will be well to fix a topographical limit. Much information has been collected dealing with various parts of our country, especially as regards Triassic and Cretaceous rocks; but I propose to limit my remarks on the whole to a large district over which I have myself worked, which may be roughly named the South-east of England, and gives I think the best illustration of the advance of this kind of knowledge within my own time.

Underground Geology in the South-east of England.

In bygone years many notices of wells or of groups of wells were certainly published; but seldom with details, in most cases only the thickness of formations being stated or merely the depth to the Chalk. Sometimes, moreover, the figures given have proved to be wrong.

So far as I know, the remarkable work of the Rev. J. Townsend, practically the first general account of the geology of England, is the first case in which reference is made to sets of wells as proving the thickness of formations, in this case of the Chalk, of the Great Oolite, and of the Inferior Oolite.[1]

Afterwards the names of Mitchell, Mylne, Clutterbuck, and Clarke are prominent among our contributors to underground knowledge, to be followed a little later by that of Prestwich. But, as a rule, their work, as above noted, did not give much detail; and it was not until 1854, when I was a student under Morris, that the first goodly collection of well-sections, with trustworthy details and modern classification of the Tertiary formations, was published, in Prestwich's great paper 'The Woolwich and Reading Series.'[2]

In this paper, one which will always rank among our classics, fifty-five wells in the London Basin are described, most of them in

[1] 'The Character of Moses established for Veracity as an Historian, recording Events from the Creation to the Deluge,' 4to, Bath, 1813 (pp. 123, 124, 129, 130). Nearly the whole of the book refers to geology rather than to Moses.

[2] Quart. Journ. Geol. Soc. vol. x, pp. 94–97, 105, 139–154.

detail. It is perhaps strange that the value of such a collection of sections, many carried to a great depth and through beds which do not crop out at the surface within considerable distances, was not at once seen. Such, however, seems to have been the case, and in preparing a Geological Survey Memoir descriptive of a tract that contained many of the sites of these wells, published ten years later, I was content to give a mere abstract of some of these sections, instead of reproducing them in full, an error of judgment that has been corrected in later Memoirs.

The collection and publication of such matters of detail is pre-eminently the work of the Geological Survey, whose Memoirs, as a rule, are intended to be works of reference rather than light literature; and during nearly 30 years that Survey has published records of many hundreds, one may say some thousands, of sections of wells and borings, chiefly in the tract with which we are now concerned, but also in other districts. Smaller, but goodly, contributions for various parts of England are to be found in the Reports of the Underground Water Committee of the British Association and in the publications of many societies and by several authors.

The detailed knowledge thus gained, as to South-eastern England, has been fruitful in general results, of which the following seem to be the more notable:—

1. In proving the thickness of the Drift at a large number of places, and in showing that this thickness is often greater, sometimes far greater, than had been expected, even to the extent of reaching to below sea-level far inland.

2. In proving that some of our Crag-beds are of much greater thickness underground than we had reason to think, from our knowledge of them where their whole thickness is seen at the surface and is small.

3. In giving us a much better idea of the extent of the Eocene Tertiaries underground than we had before, in parts where they are hidden by wide or thick coverings of Drift or of Pliocene. Over large tracts in East Anglia that are represented as Chalk on old geological maps, we now know that the Drift, etc. is next underlain by older Tertiary strata.

4. In proving the depth to the Chalk in very many places: so much indeed in our immediate neighbourhood here that it would be a fairly easy, though laborious task, to lay down on a map contour-lines of the depth to the Chalk, referred of course to Ordnance-datum, a work that I hope may be undertaken ere long.

With these four subjects goes of course a great addition to our knowledge of the various local conditions of the formations passed through, as well as of their varying thicknesses.

So far reference has been made to published information only; but in continuing these remarks I shall also occasionally have to make some use of unpublished material, whether in the hands of Prof. Boyd Dawkins and of Mr. Etheridge, both of whom I have to thank for information, or in my own. Of course, such unpublished notes are used subject to correction.

That the Chalk everywhere underlies the Tertiary of the London and Hampshire Basins is a sort of axiom, long taken for granted by all geologists; but it is nevertheless satisfactory to be able practically to prove it, from the fact that whenever a hole is dug deep enough Chalk is found: for unbelievers in matters geological are not yet extinct. The immense mass of accumulated evidence has long been enough to convince any reasonable being, and we can afford to ignore unreasonable ones, for there are more than 800 wells and borings that pass through Eocene beds to the Chalk in the London Basin.

It is different, however, when we come to the question of what next underlies the Chalk deep underground; and it is to this, the underground extension of formations older than the Chalk, that I particularly wish to draw attention, making use not only of borings for water, but of others of a more experimental kind. I hope to be forgiven for omitting references to the many authors who have contributed to our knowledge.

While we see, from our geological maps, that the Chalk occurs everywhere round the Tertiary beds of the two Basins, and mostly with a broad outcrop, it is not quite the same with the underlying Cretaceous divisions. Though the Upper Greensand and the Gault are now in fair way of being taken as parts of one formation, which it is proposed to call Selbornian, yet in the present case there is some convenience in dealing with the two separately, not using the new classification until the Geological Survey Monograph on the Upper Cretaceous formations is in our hands. First let us deal with the London Basin, including therein the Chalk as well as the Tertiary, and also taking in part of the Wealden tract.

London Basin (and Weald).

The Upper Greensand being, as a rule, comparatively thin at its outcrop and of somewhat varying character, one is not surprised to

find it absent at the surface over considerable parts of the bordering Cretaceous tract. The Gault, on the other hand, is a practically persistent mass of clay, and the only part where this clay does not occur at the surface (where lower beds crop out from beneath the Chalk of the London Basin) is far north, in North-western Norfolk, and there only the thin Red Chalk comes between the White Chalk and the Carstone of the Lower Greensand.

The Lower Greensand, in general a fairly thick formation, has a continuous outcrop round the district of the Weald, except perhaps in the far east of Sussex, where it is certainly thin and apparently sometimes absent. On the northern side of the London Basin it is occasionally wanting at the surface, owing to overlap of the Gault.

The Wealden beds, from their freshwater and estuarine nature, are more local, and though very thick on the south, in the tract from which the name is taken, are almost confined to that part, the occurrence on the north being insignificant. No one, therefore, expected to find their underground range very great.

The Chalk.

The great number of wells reaching the Chalk through Tertiary beds has been noticed, and many of these go to a considerable depth in the Chalk; but it is rather rare for a boring that starts in the Tertiary beds to pass through the Upper Chalk (the thickest division) into the Middle Chalk, and it is still more rare to find a boring that reaches down from the top of the Chalk to its base. Prestwich was the first to record any such borings, those at Kentish Town and at Harwich, and for many years these alone held the field.

In the great tract of the London Basin there are only fifteen places where such borings have been made; but at eight others nearly the whole thickness of the Chalk has been pierced, the sites being either no great distance from where the Tertiary beds come on, or so high on the Chalk that no great thickness of it can have been removed. Besides these others, beginning somewhat lower down in the Chalk, have yet pierced a considerable thickness of it.

The first new fact that we learn from these deep borings is the thickness of the Chalk; and this at its lowest is over 620 feet (at Streatham), while in the highest case it reaches to more than 1140 feet; and this latter is at Norwich, where the

top of the formation is absent: so that we have probably a difference at the rate of 2 to 1. It is shown, too, from several borings that the least thickness is in the middle part of the Basin and in our own neighbourhood here, while the greatest is in the north-east.

As regards the divisions of the Chalk not much has been learnt, but enough to indicate that all three, Upper, Middle, and Lower, extend underground, as might be expected.

The Upper Greensand.

Coming to the formations beneath the Chalk, except at sites near their outcrop there is no evidence of underground extension westward of Winkfield, near Windsor; and so, for the present, our view must be limited to that part of the London Basin which lies east of a north-and-south line from Wendover to Aldershot. There can be little doubt, however, that Upper Greensand and Gault occur throughout the tract to the west.

Eastward from Winkfield, where it is 31 feet thick, the Upper Greensand occurs in all the deep borings along the broad Valley of the Thames, at Richmond, and in London to Crossness, never exceeding the thickness at Winkfield, but irregularly decreasing to 12 feet at Crossness and to 10 at Shoreham, in the Valley of the Darent.

Beyond this eastward, in Kent, it has not again been found in any of the twelve or more borings that have been carried deep enough to prove it. This agrees with the thinning at the outcrop, no Upper Greensand that could be mapped having been found beyond a few miles eastward of the Darent, except for a short distance near Folkestone.

North of the Valley of the Thames it is absent at Bushey, near Watford, which is practically on the line between the thinning-out on the southern outcrop, at Kemsing, and the point beyond which Upper Greensand cannot be mapped on the northerly outcrop near Tring, though it is again seen a little near Dunstable.

So far, therefore, the underground evidence agrees remarkably well with that obtained aboveground. But north of London the conditions are different, the Upper Greensand extending underground in renewed force up the valley of the Lea, being 44 feet thick at Cheshunt and 40 at Ware, quite a respectable thickness for this

division so far east. It also occurs at Loughton, in Essex, where it is 30 feet thick, whence one may infer that from London a northerly extension or bay of Upper Greensand juts out.

North of the Thames eastward of the above-mentioned localities there is but little information, and what there is comes from a long way off. An old MS. description (in the Society's library) of a boring made at Coombs, near Stowmarket, Suffolk, in 1855, says that Gault and Greensand alternately, to the thickness of 21 feet, were found at the bottom, while a printed account (of 1860) definitely mentions 10 feet of Upper Greensand between Chalk and Gault; but this is not enough to warrant one in making sure of the first, as it is not uncommon for the glauconitic base of the Chalk Marl to be called Upper Greensand, and no lithological description is given.

At Harwich, again, occurs Gault mixed with Greensand, for 22 feet, which is no more satisfactory, and at Norwich we are still left in doubt. On the other hand, there are three borings in which no Upper Greensand was found, at Weeley (south-west of Harwich), at Stutton (west of Harwich), and at Culford (north of Bury St. Edmunds), and the clear evidence of these outweighs the doubtful evidence of the borings at Coombs and Harwich.

Nor is there in the northern part of Norfolk any Upper Greensand, so far as is known; thus, on the whole, it may be said that under East Anglia, with the exception of the western margin of Essex, there is probably none of it, or but a little here and there. That so thin a division should extend as far as it does is perhaps more to be wondered at, than that it should be absent over a large extent of country.

The Gault.

The Gault is the only formation below the Chalk that has any claim to the virtue of constancy in underground matters. In every one of the deep borings has it been found, and except in the far north-western part of the Norfolk Cretaceous tract, there is every reason to expect that Gault will be found in any new boring that goes deep enough. With constancy of occurrence, however, there is considerable vacillation in the matter of thickness, though not locally, only as regards places far apart. With the question of thickness alone, therefore, are we concerned.

The greatest thickness of Gault known (over 340 feet), in the district under consideration, is in the deep boring at Caterham in East Surrey, near the outcrop, which outcrop seems to have been

made a little too narrow here on the Geological Survey Map, the uppermost part of the Gault having apparently been classed with the Upper Greensand, into which, indeed, it passes up.

At Winkfield, on the west, is the next greatest thickness, 264 feet, decreasing thence eastward, along the valley of the Thames, to 201 at Richmond and to between 130 and 188 in and near London. There must be a rapid thinning northward from Caterham.

Easterly thinning from Caterham is also fairly marked, there being something more than 237 feet at Sundridge, where the very top has been removed, and at Shoreham 226.

The many borings in the valley of the Medway show a thickness decreasing from 234 feet on the south, where the river enters the Chalk tract, to 192 at and below Rochester.

Pursuing an easterly course there is no certain evidence for some distance; but the Gault ultimately thins in that direction, for at Ottinge, in the parish of Elham, it is 127 feet thick, at Ropersole (? in Barham) between Canterbury and Dover 119, and on the coast at Folkestone about 100. Although north-east of the last-mentioned place, in the two borings near Dover, it reaches a higher thickness (121 and then 144 feet), thence northward it decreases to only 63 at Margate.

Along or near the northern outcrop the thickness is over 215 feet at Long Marston, near Tring, where the top beds have been removed, and 214 at Hitchin; but this decreases underground towards London, the figure at Ware being 163.

The multitude of borings in the neighbourhood of Cambridge show a decided north-easterly thinning, the thickness varying generally from 175 to nearly 110 feet, with considerably more in a single case and considerably less in another. Farther northward the thinning continues to 90 feet at Soham, 56 at Stoke Ferry, and 20 at Narborough.

Leaving out of account the boring at Saffron Walden, of which there is no trustworthy record, but which, judging by its depth, must pass through the Gault, there are four deep borings in northern Essex and in Suffolk that certainly do so (at Weeley, Harwich, Stutton, and Culford), and in these the thickness varies from 49 to 76 feet, while in the one boring in northern Norfolk, at Holkham, it is but 10. This last shows, however, that underground the Gault clay extends northward to the coast, though at the outcrop it thins out several miles southward thereof, where its place

is taken by the Red Chalk. It is noteworthy that at Holkham both formations occur, and that this is the only case of the occurrence of Red Chalk over Gault.

We may take it, therefore, as almost proved that while the Gault clay is continuous under the London Basin, except in the north-western corner of Norfolk, there is a general but irregular thinning eastward from Winkfield, accompanied by a northerly thinning, from the outcrop in East Surrey and in Kent. It is to be noted, too, that this is also the case with the Selbornian as a whole, but more decidedly, as the Upper Greensand is absent eastward and north-eastward.

The Lower Greensand.

Putting out of consideration the great number of borings in the neighbourhood of Cambridge (made for the purpose of obtaining water from the Lower Greensand), almost all of which are either on the Chalk Marl or on the Gault, and sundry other borings also near the outcrop in various parts, mostly, indeed, on the Gault, few borings reach this formation and eight or nine only pierce it from top to bottom. Nevertheless, what is learnt of it is of more interest than what has been learnt of the Gault, for in these matters change is more charming than constancy, and the underground thinning of the Lower Greensand is a question that has been often before geologists.

There is sometimes evidence of great thinning at or near the outcrop: thus a boring at Shillingford, near Wallingford, after piercing 144 feet of Gault, proved a thickness of only 25 feet of Lower Greensand, passing then into Kimeridge Clay and thereafter through Corallian beds to Oxford Clay.

The presence of this formation at the bottom of the Winkfield boring leads one to infer that this occurrence of Lower Greensand deep underground will be found to continue to the southern outcrop, where the formation shows in force; but there is no evidence how far northward of Winkfield this continuity may reach. It may be to the outcrops to the north-west or to the north. It may be, on the other hand, that there is a thinning out, as along the northern boundary of the Gault, from west-north-west to north.

Eastward at Richmond there is a thickness of only 10 feet, although at the outcrop, some 15 miles southward, there is a goodly mass. Little farther north probably no Lower Greensand would be found, for in other borings in or near London, from Streatham

on the south to Ware on the north and to Crossness on the east, there is none, the Gault resting directly on some much older formation. One is led, however, to infer the presence of this division at Loughton, where the Gault is underlain by sand.

Never again on the north of the Thames do we get evidence of the underground occurrence of Lower Greensand in places far removed from the outcrop, until reaching Culford, in Suffolk, where a thickness of about 32 feet of beds has been classed with this formation, and on the far north at Holkham, where there are either 50 or 70 feet of it, accounts varying, and where the base may or may not have been reached. Eastward, however, from Culford the borings at Weeley, at Stutton, and at Harwich show that the Lower Greensand has thinned out.

South of the Thames, in Kent, though evidence of considerable thinning northward from the fairly broad outcrop is available, there is as yet no proof of the underground thinning out of the Lower Greensand eastward of the Darent: all the borings that have gone deep enough having demonstrated the presence of this formation. Westward of the Darent its thinning out is known, from the Crossness boring.

Along the valley of the Medway several borings have struck a good supply of water from the Lower Greensand, but in one alone, at Chatham, has it been pierced to its base, and proved to be only 41 feet thick. It certainly reaches some way farther north, to beyond Chattenden.

Farther eastward there is no evidence, except close to the outcrop, until reaching the valley of the Little Stour, at the higher point of which a boring at Ottinge, in the parish of Elham, starting in the Lower Chalk, has proved that the Lower Greensand is more than 200 feet thick, while at Ropersole, some 5 miles north-east and at a greater depth, the thickness is only 72 feet.

Again, at the workings for coal south-west of Dover, 124 feet of beds have been assigned to this formation, less than the thickness at the outcrop at Folkestone; whereas at the Convict Prison north-east of the former town the thickness has fallen to 31 feet. Unexpectedly, however, a boring at Margate, many miles farther north, has passed through more than 70 feet of what is apparently Lower Greensand, without reaching the base.

In the foregoing notes no attempt has been made to deal with the various divisions of the Lower Greensand; it seems better to leave that branch of the subject until detailed descriptions of the Kentish

borings from Mr. Etheridge and from Prof. Boyd Dawkins are published. Let it suffice to say now that the Hythe Beds seem the most apt to thin out. In like manner details of the Wealden, Jurassic, and other formations will be passed by.

The Wealden and Purbeck Beds.

We have seen how considerable is the rate of thinning of the Lower Greensand underground from its outcrop; but it is small as compared with that of the much thicker Wealden Beds, with which it is here convenient to associate the Purbeck. From the fact that there are but traces of the Wealden Beds on the north of the London Basin, with little also of the Purbeck Beds, it is evident that these formations must disappear somewhere under the middle part of the Basin.

But before noticing this thinning more attentively, let us give some passing consideration to what has been already learnt of late by works carried to some depth in the Wealden district itself. The chief result perhaps is that our estimates of the thickness of the various divisions have been shown to be often too small, taking Topley's admirable Survey Memoir on the Weald as our standard, the maximum thicknesses therein assigned having been passed, and that not rarely. This, by the way, is a sign of the excellence of that Memoir, for probably the general tendency of writers is to luxuriate in high figures: temperance is not always the easiest virtue.

Perhaps the most notable boring from this point of view is that at Penshurst, which, beginning low down in the Series, in the Ashdown Beds, has not passed through the Wealden-Purbeck Series until reaching a depth of perhaps 1500 feet. This boring, too, is an illustration of another point that has been brought out by various borings: that is, the frequent difficulty of fixing divisional planes in this great set of deposits, especially when dealing with specimens brought up from considerable depths.

The trial-boring at Pluckley is of much interest also. Starting on the Weald Clay, and some way from the top of that formation, it has proved a thickness of no less than 720 feet thereof, whereas the underlying Hastings Beds are only 195 feet thick. I believe that there is also some sign of Purbeck Beds in this boring.

Returning to the subject of the northerly thinning of the Wealden beds as a whole, at Richmond there is no sign of them, although that boring is not 16 miles from the nearest outcrop of the Weald Clay.

At Streatham and Crossness it is the same, though the borings there are respectively only 14 and 18 miles from that outcrop. The like statement holds good too of Chatham, where the deep boring at the dockyard is about 13 miles from the main outcrop, but only about 8 from that of the Maidstone inlier.

In all the more northerly borings these beds are absent: indeed, so far as we know, it is only in East Kent that they reach to any great distance under the Chalk tract and are then but thinly represented, less than 250 feet at Ottinge (some 5 miles from the outcrop), only 55 at Ropersole, and 94 at the Dover Colliery.

At Hothfield, in the Lower Greensand tract west of Ashford, the thickness seems to be only about 600 feet; and at Brabourne, on the Gault east of the same town, about 200 less.

One fact, therefore, to be clearly learnt from the deep borings in Surrey and in Kent, is the rapid northerly thinning of the very thick Wealden-Purbeck Series.

The Jurassic Beds.

Up to this point formations that occur at the surface in the South-east of England, the district with which we are specially concerned, have been dealt with. We may now pass to beds not seen in that district.

Before any of the deep borings were made nothing was known as to what formations occurred beneath the Purbeck Beds of the Wealden tract, and these were the oldest known beds in the district. The great experimental boring of the Sub-Wealden Exploration, in the parish of Mountfield, near Battle, carried on the downward series in Eastern Sussex continuously through the Upper Jurassic, in great thickness, and well into the Middle Jurassic, ending in Oxford Clay at a depth of more than 1900 feet.

For some time this remained the only evidence of Jurassic beds underground within a great distance, the earlier borings at Kentish Town and at Harwich having proved the absence of such beds far off north-west and north-north-east; but further evidence is now available.

As regards the Upper Jurassic division, the westernmost occurrence is at Penshurst, where the boring ends in Kimeridge Clay of considerable thickness at the depth of 1867 feet. The most northerly evidence is at Ropersole, where there may be 10 feet of that clay, between Purbeck Beds and Corallian. The Pluckley boring ends, as

yet, in a thick mass of Kimeridge Clay, at the depth of 1397 feet. At Brabourne there are some 250 feet of the Upper division (chiefly Kimeridge Clay, but with a little Portlandian). At Ottinge and at Dover this division also occurs.

The Middle Jurassic division reaches farther northward, to Chatham, where Oxford Clay next underlies the Lower Greensand. At Brabourne both Corallian and Oxfordian occur, with a total thickness of nearly 550 feet, at Ropersole about 300 feet of those formations, and they are also found at Dover; but we have no sign of them yet farther westward or northward than the places named. Southward, in the Sub-Wealden boring, more than 220 feet of beds above the Oxford Clay have been classed as Corallian.

The Lower Jurassic division has a still wider range, occurring in two of the London borings (Meux's and Streatham) as well as at Richmond. North of London all the evidence we have is that of absence, as also at Crossness, on the east; but the trial-borings for coal at Brabourne, at Ropersole, and near Dover prove the existence of Lower Jurassic beds farther east, to the thickness of 189, 164, and 156 feet respectively.

We see then that, in every boring in which Jurassic beds have been found, the Lower division is represented wherever the borings are deep enough to reach it, and that the same is the case for the Middle division in every boring that has pierced through the Upper. On the other hand, there is one case (Chatham) where the Upper division is absent, the Middle occurring next beneath Lower Greensand, and there are three cases where the Lower division alone is present, next beneath the Gault, in and near London. Further, in one only of the London borings north of the Thames, and that the most southerly (Meux's), are Jurassic beds of any sort present on that side of the river, all the borings farther north that go deep enough showing nothing between the Cretaceous and very much older rocks.

This successive northerly thinning of the Upper, Middle, and Lower Jurassic divisions seems to point to the connexion of the underground Jurassic beds with masses farther south, and not with those of the northern outcrop. But what may happen west of Richmond we know not.

The Lias and the Trias.

Of that thick and mostly clayey formation the Lias, no sure sign was forthcoming until the Brabourne boring some two years ago

proved its presence in East Kent. Since then it has also been found at Ropersole.

This discovery seems to me most interesting, nothing of the sort having been found in the twelve other borings that have gone deep enough, unless some of the beds in the Dover boring should be classed as Lias.

At Brabourne there may be some Upper Lias, and certainly both the Middle and Lower divisions are represented, the total thickness being 172 feet. But at Ropersole, to the north-east, the formation is much thinner, consisting of only 3 feet of the Upper division and over 24 of the Middle, with none of the Lower.

With regard to the Trias we were left in doubt for many years. At Kentish Town, Richmond, Streatham, and Crossness various red rocks were found at the bottom of the borings; but what their age is we know not. They may be Triassic, or Old Red, or both, with stained Carboniferous thrown in; though the changing balance of evidence seems to have veered against the first conclusion. We could not then say that the Trias was represented underground in the South-east of England before the time of the Brabourne boring, deep down in which (from about 1876 to 1925 feet) there has been found a conglomerate associated with red-and-grey sandy marls. This conglomerate contains, among other things, pebbles of Carboniferous Limestone, and has much the aspect of the Dolomitic Conglomerate of the West of England, which presumably it represents. The Brabourne boring has an additional interest from this unexpected find, the only one of the sort.

The Older Rocks.

We have now done with the Secondary formations, and come to the perhaps still more interesting question of the older rocks beneath.

Of the Permian there is as yet no evidence, of the Carboniferous not much. The slaty rock at the base of the Harwich boring has hitherto been classed as of Lower Carboniferous age; but later evidence, from the neighbouring borings of Stutton and Weeley, and from Culford, the next nearest, has led some of us to doubt this and to think that this rock may be much older. One has been, somewhat reluctantly, forced to the conclusion that all the bottom-rock in those three more recent borings is pre-Carboniferous, and there is some family likeness in all four cases, as perhaps you may some day hear in more detail.

Beyond the district to which I specially allude, Coal Measures have been found deep underground in the Jurassic district at Burford in Oxfordshire. At and near Northampton, Carboniferous Limestone was found in the town next beneath beds of doubtful age, at 527 feet below Ordnance-datum; while at Gayton the same formation, thinly covered by Trias, comes up to 417 feet below O.D., being soon itself underlain by beds that may belong to the Old Red Sandstone; and at Orton a quartz-felsite was found only 341 feet below O.D. Of the bottom-rock in the Bletchley boring, farther south, one cannot speak with certainty.

Putting the Harwich boring aside, the first proof of the existence of Carboniferous rocks in South-eastern England was furnished by the trial-boring near Dover, which has passed through more than 1000 feet of Coal Measures. The Ropersole boring has lately reached the same formation, and these two are the only decided evidence of Carboniferous rocks that we possess.

At Brabourne the boring ends in a dark grey rock, with a dip of 60°: what it may be is unrevealed. Mr. Etheridge simply says 'not Carboniferous,' Prof. Boyd Dawkins takes it to be Devonian, while I feel inclined to allow it to be anything from Carboniferous to Silurian; but I have seen so little of it that this opinion is of small value.

As in the West of England the Dolomitic Conglomerate occurs fringing an outcrop of Carboniferous Limestone, so may we expect it to do in the East, as Prof. Boyd Dawkins has suggested; but on what side of Brabourne that is likely to happen is not certain. In this particular again the boring there is of high interest. That at Ottinge, being practically midway between this and Ropersole, would be likely to yield information of importance, and I agree with Prof. Boyd Dawkins in regretting that it has been given up without passing through the Jurassic beds.

Descending in the geological scale, we at the same time have proof of still older rocks and of the absence of Carboniferous rocks at various places north of the Thames—and, if we allow that the doubtful red rocks are more likely to be of Old Red than of New Red age, in others south of the Thames also. There is no need to deal in detail with these older rocks, as most of them have been discussed at length in publications with which you are familiar, while the oldest (apparently) will have to be noticed in some paper to come.

Rocks of undoubted Devonian age have been found in two places only, in London (at Meux's) and at Cheshunt; while undoubted

Silurian occurs farther north, at Ware, and presumable Silurian or still older rock far to the north-east, at Culford, Stutton, Weeley, and perhaps Harwich. In most of these cases, moreover, there is no sign of any newer rock until we reach the Gault. At Culford only very little Lower Greensand occurs, at Meux's only a little Jurassic.

When we examine the position of the various older rocks as regards their relation one to the other, and the height which they reach, we find firstly that, as a rule, older and older formations rise in succession northward, so as to come next beneath the Secondary beds, and no boring so far has passed into more than one of these older rocks. Secondly it is, as a rule, the oldest rocks that reach the highest levels underground, at Culford and at Ware, while the newest (Carboniferous) are at the lowest levels near Dover, leaving out of question the doubtful beds.

That this arrangement is universal, of course, one has no right to expect: there must be folds and faults, giving rise to troughs or basins, though as yet no proof of such has been brought forward. So far as we have gone, therefore, a structure usual among old hill-ranges has been found, the older beds rising to the higher levels. It seems indeed that there is beneath us the eroded remains of such a range, the sides of which were laved successively by Jurassic and by Cretaceous seas; but this old range apparently was not wholly submerged until the time of the Gault. Nor is there yet any evidence of a Gault shore: no conglomerate has yet been found at the base of the Gault, no pebble of the older rocks in the Gault, that formation showing in every boring its usual clayey character, which points to tranquil deposition.

Hampshire Basin.

The important subject to which your attention has been drawn is one that has arisen within my own time, and that in and around one of the best known geological districts in the world, the London Basin. Our knowledge of the underground structure of this large tract has been vastly advanced.

We are also considerably wiser with regard to the great Wealden district to the south, including therein the outcrop of all formations below the Chalk. But when we go farther southward and westward to that other large tract known as the Hampshire Basin, including the Chalk again (and extending over parts of other counties

than that from which the name is taken), our increased knowledge is less and goes down to a less geological depth.

We have certainly learnt much as to the thickness of various divisions of the Tertiary both in Sussex and in Hampshire, and also of their underground extension, especially under the far-spreading mantle of Drift that reaches for some miles inland from the coast in great part of the former county, as shown on the new Geological Survey maps. The old maps indeed must often have been mere guesses in this matter, no evidence having been then obtained over the vast flat surface of the Drift tract.

We have, of course, at the same time learnt something of the depth to the Chalk, through the Eocene Tertiaries; but only by means of some 22 wells and borings in Sussex and as many in Hampshire. This small total of 44 is not an eighteenth of that in the London Basin.

As to the thickness of the Chalk under the Tertiary in the Hampshire Basin, this was known before the time of which I have been treating, by the boring at Chichester, passing through 790 feet of Chalk, from top to bottom; and we also knew that at Southampton there was a greater thickness, over 850 feet having been passed through without reaching the bottom. The only additional information gained is from the Warren Farm Well at Telscombe, east of Brighton, which, starting from only a few feet below the top, proves a thickness of nearly 960 feet. At the outcrop in the Isle of Wight the thickness is much greater than this; and it seems therefore that, as in the London Basin, there is some thinning towards the middle; but it is unsafe to generalize much from such scanty evidence.

While at Chichester a thickness of over 80 feet of Upper Greensand was found, without reaching the base, at Telscombe there are but 10 feet of this division, and in this latter place alone (except in parts outside the Chalk-escarpment) has the Gault been reached. It has, however, been pierced to the base, giving the high thickness of 312 feet and being apparently underlain by Lower Greensand.

Along the border of the Chalk in Eastern Sussex it has been proved that the Gault is much thicker than had been thought, ranging up to more than 300 feet indeed, in one case 345, or a trifle more than at Caterham. It has also been found that the Lower Greensand is very thin and sometimes absent, the Gault then resting on Weald Clay.

Except, therefore, in the neighbourhood of the outcrops of the

Lower Greensand and the Weald Clay, where we may fairly infer extension underground, and for the one boring at Telscombe, we are still left in utter ignorance as to what formations next underlie the Upper Cretaceous in the Hampshire Basin. Indeed there are places near the border of Hampshire and Berkshire, in what may be called the neutral land between the Hampshire and the London Basins, where we do not know what may be found 300 or 400 feet down, as in the Upper Greensand inliers of Kingsclere and of Shalbourn, especially in the former, where one cannot safely infer anything below the Gault, the top of which can hardly be far down at some spots, though I believe that even this has never been proved. On Sheet 81 of the so-called Horizontal Sections of the Geological Survey, published in 1870, the Gault is shown as underlying the Upper Greensand here, with Kimeridge Clay next beneath; but I have failed to find any evidence for this inference, and am fain to conclude that the author, who was taken from us many years ago, feeling bound to fill the section in to sea-level, made the best guess that he could, based on the fact that at the distant outcrop to the north that succession holds on the map, for some distance.

Enough has now been said on the subject of the underground extension of beds, as proved by wells and borings in one part of England, to show how the subject itself could be extended. Other parts of our own country tell a like story, and in other countries similar work has been done, in many cases to much greater depths than with us, as in Germany and in the United States.

Much then have we learnt, but much more have we yet to learn, and that, it seems to me, is the moral that we should draw from our retrospect. I remember how in my earlier days it was said that the older geologists had done all the grand work, and that we, their successors, would have to be content with the humbler task of filling in the details of the great pictures which they had sketched out. Has it been so? Certainly not. The work of many of us, including myself, may have been mostly of this detailed nature, consisting largely of the collecting together of masses of facts, but those collections of facts have sometimes led to new views that have had a great effect in the advancement of our science. Moreover, many of the subjects to which I have but briefly alluded are as

great as those with which our forerunners successfully grappled, and there are many matters to which I have made no allusion, including the applications of geology to various practical purposes.

As it has been, so it will be. Fresh lines of thought, new means of work, will lead the geologists of the future to researches yet undreamt of, to conceptions beyond our powers. Greater accuracy of detail, combined with wider knowledge of the world, will not take the place of, but will be accompanied by, broader and grander views of the structure of our globe. And glad am I to think that it should be so, to feel that we, the older geologists of the present time, will be succeeded by others better prepared for their great work, better able to sustain the high reputation of this Society and of English geology.

To our younger members I say that we hand over to you an improved heritage: it is for you to further improve it and so to pass it on to your successors. In the same way that we have reverenced the work of those who went before, so doubtless will you, who follow us, look with kindly eyes upon our work.

In vacating this chair I have the pleasure of welcoming as my successor one who both by age and by work is well-fitted to preside over you during the passage from one century to another: one who has done much, but from whom we can expect a good deal more, one who is in that safe middle way between the older and the younger geologists. Taking upon myself the character of representative of your older members, I may address him, after the fashion of the gladiators of old, but in no doleful strain: Hail, President! Those whose work is nearing its end greet you!

February 21st, 1900.

J. J. H. TEALL, Esq., M.A., F.R.S., President, in the Chair.

The Rev. E. C. Spicer, B.A., University Museum, Oxford, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Bunter Pebble-Beds of the Midlands and the Source of their Materials.' By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.

2. 'Further Evidence of the Skeleton of *Eurycarpus Oweni*.' By Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S.

The following specimens and maps were exhibited:—

Bunter Pebbles and Microscopic Sections of the same, exhibited by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S., in illustration of his paper.

Casts of Remains of *Eurycarpus Oweni*, exhibited by Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S., in illustration of his paper.

Quartzite-pebble, with Casts of Fossils from Barnt Green (Worcestershire), exhibited by O. A. Shrubsole, Esq., F.G.S.

Pebbles from Hopwas, near Tamworth (Staffordshire), collected by S. H. Warren, Esq., F.G.S., and exhibited by A. E. Salter, Esq., B.Sc., F.G.S.

Carte géologique de la Suisse: Sheet 16, 2nd ed., by E. Renevier, H. Schardt, & M. Lugeon, on the scale of $\frac{1}{100,000}$, 1899. Presented by the Geological Survey of Switzerland.

Geological Map of Cue, Peak Hill, & Menzies, by A. G. Maitland, on the scale of 1 inch = 23 miles, 1899. Presented by the Geological Survey of Western Australia.

March 7th, 1900.

J. J. H. TEALL, Esq., M.A., F.R.S., President, in the Chair.

Henry William Burrows, Esq., 94 Elm Park, Brixton, S.W.; John Cadman, Esq., B.Sc., Silverdale House, Silverdale (North Staffordshire); William Campbell, Esq., B.Sc., 44 Dawes Road, Walham Green, S.W.; Henry Brougham Dutton, Esq., B.A., B.Sc., College View, West Road, Congleton; Gerald Harnett Halligan,

Esq., Government Works Department, Sydney (New South Wales); William Frederick Holmes, Esq., B.A., Imperial Institute, South Kensington, S.W.; Thomas Aloysius O'Donahue, Esq., 35 Princess Street, Wigan; and Walter G. Woolnough, Esq., B.Sc., Assistant Lecturer in Mineralogy and Demonstrator in Geology, University of Sydney (New South Wales), were elected Fellows of the Society.

The following communications were read:—

1. 'Notes on the Geology of Gilgit.' By Lieut.-Gen. C. A. McMahon, F.R.S., F.G.S.
2. 'The Rocks of the South-eastern Coast of Jersey.' By John Parkinson, Esq., F.G.S.
3. 'The Rocks of La Saline (Northern Jersey).' By John Parkinson, Esq., F.G.S.

The following specimens were exhibited:—

Rock-specimens from Gilgit, Microscope-sections, and Lantern-photographs, exhibited by Lieut.-Gen. C. A. McMahon, F.R.S., F.G.S., in illustration of his paper.

Rock-specimens from Jersey and Microscope-sections, exhibited by John Parkinson, Esq., F.G.S., in illustration of his two papers.

March 21st, 1900.

H. W. Monckton, Esq., F.L.S., Vice-President, in the Chair.

Stanley Walkington Carpenter, Esq., Trevathan, Beckenham (Kent); Thomas John Jehu, Esq., B.A., M.B., B.Sc., St. John's College, Cambridge; and the Right Rev. John Mitchinson, D.C.L., D.D., Master of Pembroke College, Oxford, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On a Bird from the Stonesfield Slate.' By Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S.
2. 'The Lower Ludlow Formation and its Graptolite-Fauna.' By Miss E. M. R. Wood. (Communicated by Prof. C. Lapworth, LL.D., F.R.S., F.G.S.)

The following specimens and maps were exhibited:—

Cast of a Fossil Bird-bone, exhibited by Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S., in illustration of his paper.

Specimens of Lower Ludlow Graptolites and Lantern-slides, exhibited by Prof. C. Lapworth, LL.D., F.R.S., F.G.S., in illustration of the paper by Miss Ethel M. R. Wood.

Geological Survey of England & Wales: 1-inch Geological Map, n. s., no. 231, Merthyr Tydfil (Solid & Drift) by A. Strahan, W. Gibson, & T. C. Cantrill, 1900; also no. 325, Exeter (Drift) by W. A. E. Ussher, 1899, presented by the Director-General of H.M. Geological Survey.

April 4th, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

Charles George Warnford Lock, Esq., 4 Throgmorton Avenue, E.C.; William Rofe, Esq., 8 Victoria Street, Westminster, S.W. Alfred Godden Smith, Esq., Naishcombe House, Wick, near Bristol and Theodore Stacey Wilson, M.D., B.Sc., M.R.C.P., Wyddrington, Edgbaston, Birmingham, were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced that Mr. F. W. Harmer had presented to the Society an enlarged photograph, suitably framed, of Messrs. Searles Wood, father and son; and thanked the donor for this opportune addition to the Society's collection of portraits of eminent geologists.

The following communications were read:—

1. 'Additional Notes on some Eruptive Rocks from New Zealand.' By Frank Rutley, Esq., F.G.S.

2. 'On the Discovery and Occurrence of Minerals containing Rare Elements.' By Baron A. E. Nordenskiöld, F.M.G.S.

The following specimens and lantern-slides were exhibited:—

Microscope-sections and hand-specimens of Eruptive Rocks from New Zealand, exhibited by Frank Rutley, Esq., F.G.S., in illustration of his paper.

Lantern-slides photographed and exhibited by Frederick Chapman, Esq., A.L.S., F.R.M.S., in illustration of the same paper.

April 25th, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

Dr. Sven Leonhard Törnquist, of Lund (Sweden), was elected a Foreign Member; and Prof. Federico Sacco, of Turin, was elected a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

The President, having requested all present to rise from their seats, read the following resolution which had been passed unanimously by the Council: 'That this Council desire to place on record their deep sense of the loss which both science and literature have sustained in the death of the Duke of Argyll, who was the oldest surviving past-President of the Geological Society;' and stated that on behalf of the Council he proposed to communicate a copy of the resolution to the Duchess of Argyll, coupled with an expression of respectful sympathy.

The following communications were read:—

1. 'On an Anomodont Reptile, *Aristodesmus Rütimeyeri* (Wiedersheim), from the Bunter Sandstone near Basel.' By Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S.

2. 'On Longmyndian Inliers at Old Radnor and Huntley (Gloucestershire).' By Charles Callaway, M.A., D.Sc., F.G.S.

The following specimens, lantern-slides, and maps were exhibited:—

Specimens of Native Gold, apparently Pseudomorphous after Wood, from near Port Darwin (Northern Territory of South Australia), exhibited on behalf of O. C. Witherden, Esq., by Prof. W. W. Watts, M.A., Sec.G.S.

Casts showing portions of the Skeleton of an Anomodont Reptile from the Bunter Sandstone of Riehen, near Basel, exhibited by Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S., in illustration of his paper.

Rock-specimens, Microscope-sections, and Lantern-slides of Longmyndian Rocks, exhibited by Dr. Charles Callaway, M.A., F.G.S., in illustration of his paper.

Geological Map of South Australia, 1899, on the scale of 16 miles to the inch, drawn up and presented by H. Y. L. Brown, Esq., F.G.S., Government Geologist of South Australia.

May 9th, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

Donald Alexander MacAlister, Esq., Jebel Sikait (Red Sea Desert), Egypt, and 20 Hanover Square, W., was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Pliocene Deposits of the East of England.—Pt. II: The Crag of Essex (Waltonian), and its Relation to that of Suffolk and Norfolk.' By F. W. Harmer, Esq., F.G.S. With a Report on the Inorganic Constituents of the Crag, by Joseph Lomas, Esq., F.G.S.

2. 'A Description of the Salt-Lake of Larnaca, in the Island of Cyprus.' By C. V. Bellamy, Esq., F.G.S., Assoc.M.Inst.C.E.

The following specimens were exhibited:—

Specimens of Crag Mollusca, exhibited by F. W. Harmer, Esq., F.G.S., in illustration of his paper.

Sand-grains and Minerals occurring in Red Crag, Norwich Crag, and Chillesford Sand, exhibited by J. Lomas, Esq., F.G.S.

Specimens of Mollusca, etc., from Cyprus, exhibited by C. V. Bellamy, Esq., F.G.S., Assoc.M.Inst.C.E., in illustration of his paper.

May 23rd, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

John T. Hotblack, Esq., Newmarket Road, Norwich; Herbert Nuttall, Esq., Ferns Holme, Bury; and Joseph Charles Sims, Esq., Principal of the Witney School of Science, Witney (Oxfordshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Igneous Rocks of the Coast of County Waterford.' By F. R. Cowper Reed, Esq., M.A., F.G.S.

2. 'On Kentallenite and its Relations to other Igneous Rocks in Argyllshire.' By J. B. Hill, Esq., R.N., and H. Kynaston, Esq., B.A., F.G.S.

The following specimens and lantern-slides were exhibited :—

Specimens of Kaolin and Auriferous Conglomerate from British Guiana, exhibited by T. S. Hargreaves, Esq., F.G.S.

Rock-specimens and Microscope-sections of Igneous Rocks from the Coast of County Waterford, exhibited by F. R. Cowper Reed, Esq., M.A., F.G.S., in illustration of his paper.

Lantern-slides of Microscopic Rock-sections, etc., exhibited by J. B. Hill, Esq., R.N., and H. Kynaston, Esq., B.A., F.G.S., in illustration of their paper.

June 6th, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

The names of certain Fellows were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-payment of Arrears of Contributions.

The List of Donations to the Library was read.

The following communications were read :—

1. 'Mechanically-formed Limestones from Junagarh (Kathiawar), and other Localities.' By Dr. J. W. Evans, LL.B., F.G.S.

2. 'Note on the Consolidated Æolian Sands of Kathiawar.' By Frederick Chapman, Esq., A.L.S., F.R.M.S. (Communicated by Dr. J. W. Evans, LL.B., F.G.S.)

3. 'On Ceylon Rocks and Graphite.' By A. K. Coomára Swámy, Esq., F.G.S.

The following specimens, photographs, maps, etc., were exhibited :—

Fossil Turtle Eggs from Ascension, and Pliocene Limestones from Bermuda and the Bahama Islands, in the Society's Collection; other specimens from Kathiawar, etc.; together with Microscope-sections and Lantern-slides, exhibited in illustration of the papers by Dr. J. W. Evans, LL.B., F.G.S., and Frederick Chapman, Esq., A.L.S., F.R.M.S.

Specimens and Microscope-sections of Ceylon Rocks, and Lantern-slides, exhibited by A. K. Coomára Swámy, Esq., F.G.S., in illustration of his paper.

Photographs of Ammonites, exhibited by S. S. Buckman, Esq., F.G.S.

New Edition of the $\frac{1}{500,000}$ Map of the Geological Survey of Portugal, by J. F. N. Delgado and P. Choffat, presented by the Commissão dos Serviços geologicos de Portugal.

Globe orogénique de la Terre, d'après F. Sacco, scale $\frac{1}{100,000,000}$, illustrating his memoir on the Orogeny of the Earth, presented by the Author.

June 20th, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

David Watkin Jones, Esq., 5 Llantwit Street, Cardiff; Paul Mellors, Esq., Minas San Crispin, La Majada, Huelva (Spain), and Locksley House, Sherwood Rise, Nottingham; Albert Henry Pawson, Esq., Farnley, Leeds; Edward Potter, Esq., J.P., Murray Street, Gawler (South Australia); and Thomas Sheppard, Esq., Eastbourne Villas, 432 Holderness Road, Hull, were elected Fellows; Prof. Paul Groth, of Munich, was elected a Foreign Member; and Prof. Arturo Issel, of Genoa, a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

The names of certain Fellows were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-payment of Arrears of Contributions.

The President announced that the Foreign Secretary had received the following letter from Prof. A. Gaudry, F.M.G.S., President of the Organizing Committee of the VIIIth International Geological Congress:—

'My Dear Friend,

'We have just published the Guide-book to the excursions in France of the International Geological Congress. It occupies over 1000 pages, and is full of beautiful illustrations and of geological sections and maps. The excursions will extend over the whole of France, from the North as far as the Central Plateau, the Alps, and the Pyrenees. As you are the Foreign Secretary of the Geological Society of London, equally honoured and loved in England and in France, I think that no one is in a better position than you to beg of the Fellows of the Geological Society of London to come in large numbers to Paris. All our geologists will be honoured in seeing them, and will be happy to receive their opinions. To have any great authority, it is necessary that an International Geological Congress should have your country—where Geology has been so magnificently studied—largely represented. You can tell our brethren of the Geological Society of London that the President of the Organizing Committee of the Congress of 1900 is the oldest of the Foreign Members inscribed upon their list, that he is a former recipient of the Wollaston Medal, a Foreign Member of the Royal Society of London, and that among his scientific acquaintance he has not a better friend than you. This will be as much as to tell them that I am attached to them by the bonds of deep gratitude, and that it will be a happiness for me to welcome them in our ancient city of Paris. I reckon upon you.

'Yours most sincerely,

'Albert Gaudry.'

The following communications were read:—

1. 'On the Skeleton of a Theriodont Reptile from the Baviaans River (Cape Colony).' By Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S.

2. 'Fossils in the Oxford University Museum.—IV: Notes on some Undescribed Trilobites.' By H. H. Thomas, Esq., B.A., F.G.S.

3. 'On Radiolaria from the Upper Chalk at Coulsdon (Surrey).' By W. Murton Holmes, Esq. (Communicated by W. Whitaker, Esq., B.A., F.R.S., F.G.S.)

The following specimens, photographs, and maps were exhibited:—

Casts of Reptilia, exhibited by Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S., in illustration of his paper.

Specimens, Drawings, and Lantern-slides of Trilobites from the Oxford University Museum, exhibited by H. H. Thomas, Esq., B.A., F.G.S., in illustration of his paper.

Specimens from the Upper Chalk at Coulsdon (Surrey), exhibited by W. Murton Holmes, Esq., in illustration of his paper.

Eoliths from the *Elephas-meridionalis* bed, Dewlish (Dorset), and from the Southern Drift, Alderbury (Wilts), found by Dr. H. P. Blackmore, exhibited by the Rev. R. Ashington Bullen, B.A., F.G.S.

Graptolites from Bedruthan (Cornwall), exhibited by Upfield Green, Esq., F.G.S.

Photographs illustrating the Structure of Eastern Sinai, exhibited by Dr. W. F. Hume, F.G.S.

Sheets 37 & 38 (new edition) of the Geological Survey of Ireland 1-inch Map, presented by the Director-General of H.M. Geological Survey.

Sheets 2 & 10 (new edition) of the Geological Survey Map of Spain, presented by the Geological Commission of that kingdom.

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OF

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Fellows on election pay an Admission Fee of Six Guineas. The Annual Contribution paid by Fellows is Two Guineas, due on the 1st of January in every year, and payable in advance; but Fellows elected after the month of February are subject only to a proportionate part of the Contribution for the year in which they are elected, and Fellows elected in November or December pay no Contribution for the current year. The Annual Contribution may at any time be compounded for by a payment of Thirty-Five Pounds.

The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling prices.

The Library is open daily to the Fellows between the hours of 10 and 5 (except during the fortnight commencing on the first Monday in September), and on Meeting Days until 8 P.M.: see also next page. Under certain restrictions, Fellows are allowed to borrow books from the Library.

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